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September 1995

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Waterways Experiment
Station

Design, Development, and Operation of the Multiport Sampler

by Daniel A. Leavell, Landris T. Lee, Jr.

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Waterways Experiment Station
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Final report

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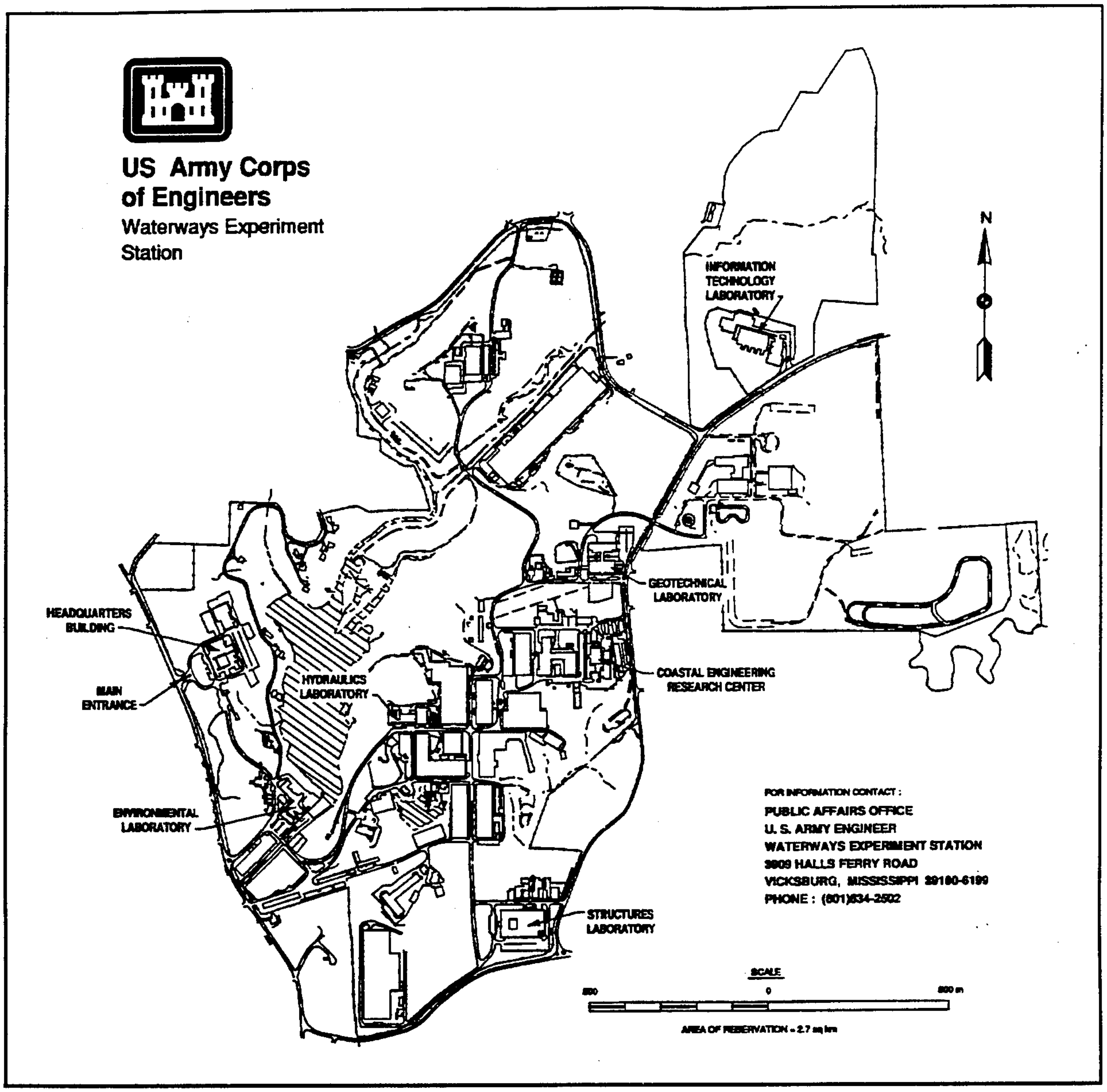

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Preface

The U.S. Army Engineers Waterways Experiment Station (WES), under the sponsorship of the U.S. Army Environmental Center (AEC), designed and developed the Multiport Sampler (MPS), an innovative sampling technology readily adaptable to the Site Characterization and Analysis Penetrometer System (SCAPS). The MPS is one product of that effort. Preparation of this report was funded by the Strategic Environmental Research and Development Program (SERDP) and AEC.

The design and development of the MPS was conducted by a multidisciplinary team composed of personnel from the Geotechnical Laboratory (GL), Structures Laboratory (SL), and the Environmental Laboratory (EL). The personnel included Mr. Daniel A. Leavell (GL), Dr. John F. Peters (GL), Mr. Stafford S. Cooper (GL), Dr. Philip G. Malone (SL), Mr. Landris T. Lee (GL), and Dr. Richard W. Peterson (GL). The Contaminant Trap and Direct Measuring Ion Trap Mass Spectrometer were developed and adapted to the MPS by Oak Ridge National Laboratory (ORNL) personnel.

The laboratory testing of the MPS at WES was performed by Mr. Leavell and Dr. Peterson, GL, and Mr. Johnny Morrow and Mr. Eric Smith, Information Technology Laboratory (ITL). The laboratory testing of the MPS at ORNL was performed by Messrs. Leavell and Lee and Dr. Peters, WES, and Messrs. Ralph Ilgner and Rob Smith and Dr. Roger Jenkins, ORNL. The cooperative field testing of the MPS at Savannah River Integrated Demonstration Site (SRS) was performed by Messrs. Leavell, Lee, Karl Konecny, GL, Don Harris, Directorate of Public Works, Jeff Powell and Bryan Register, ITL, Roy Wade, and Dr. Bill Davis, EL, WES, and Messrs. Ilgner and Cyril Thompson and Dr. Marc Wise, ORNL.

This report was prepared by Messrs. Leavell and Lee.

The project was supervised by Mr. Joseph R. Curro, Jr., Chief, Engineering Geophysics Branch, Dr. A. G. Franklin, Chief, Earthquake Engineering and Geosciences Division, Dr. Don C. Banks, Chief, Soil and Rock Mechanics Division, and Dr. W. F. Marcuson III, Director, GL. The project was under the WES management of Mr. John H. Ballard, SCAPS Assistant Program Manager, EL; Dr. Jerome L. Mahloch, SCAPS Program Manager, WES Executive Office; and Dr. John Harrison, Director, EL. The AEC Project Officer was Mr. George E. Robitaille.

The Director of WES during the research, development, and report preparation was Dr. Robert W. Whalin. The Commander was COL Bruce K. Howard, EN.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
feet	0.3048	meters
inches	2.54	centimeters
Fahrenheit degrees	(5/9) (F - 32)	Celsius degrees
pounds (force) per square inch	6.89476	kilonewton per square meter
tons (short ton)	907.2	kilograms

1 Introduction

Background

The Multiport Sampler (MPS) exemplifies innovative technology developed for the purpose of subsurface soil characterization and assessment using the direct push (cone penetrometer) method. The MPS was developed by the U.S. Army Engineer Waterways Experiment Station (WES) within the Tri-Service Site Characterization and Analysis Penetrometer System (SCAPS) program under the sponsorship of the U.S. Army Environmental Center (AEC).

SCAPS trucks are capable of hydraulically pushing a steel pipe string into soil and uncemented geologic media to depths of approximately 150 ft. The steel pipe may contain one or more attachments consisting of specialized sensors or sampling equipment. The penetrometer-based platform is more economical and efficient than conventional drilling technologies for conducting rapid site characterization studies. The capabilities of the SCAPS are described by Cooper et al. (1988 and 1993) and Robitaille (1994).

The MPS was developed to provide the cone penetrometer system with a more effective means of obtaining soil vapor and liquid samples. Present technology does not have a capability for taking multiple fluid samples during a single direct push without cleaning of the sampling port during the penetration event. The MPS was developed to overcome the shortfalls in the samplers that are currently available, and consists of a series of vertically stacked port modules which are independently operated during sampling. As the cone penetrometer advances to a desired depth, the modules are selectively opened to allow entrance of soil pore vapor and/or liquid. The vapor and/or liquid samples may then be analyzed for suspected contaminants or stored for other purposes. The collection lines from the MPS can be attached to an Ion Trap Mass Spectrometer (ITMS) or other appropriate instrumentation for direct analysis of contaminants. The MPS unit is the only sampler that is designed to allow soil strength measurement to be made during the same push that samples are taken and to permit grout to be injected into the penetrometer hole as the probe is retracted. A patent (U.S. Patent Office 1994) has been granted for the MPS system.

Purpose

The purpose of this report is to describe the MPS components, detail the assembly sequence, and provide field-tested procedures for integration of the MPS with cone penetrometer equipment. The report is divided into several sections beginning with component descriptions, proceeding to assembly (and disassembly) sequence descriptions, and concluding with system integration logistical descriptions.

Although specifically developed for the SCAPS, the MPS system does not contain equipment unique to SCAPS. The MPS probe interfaces only with the hydraulic ram (during direct pushing) and the signal conditioning circuits (for the cone tip and friction sleeve output voltages of the electric cone). The tubes connecting the modules to the surface are terminated at the MPS control console. No computer software is required for the MPS unless the cone tip and friction sleeve outputs are converted into soil classification algorithms (furnished with the SCAPS) or unless data collection and/or analysis requires computer capability. However, the usefulness of the MPS system is greatly enhanced when the soil classification scheme is used to provide real-time soil-type identification as the probe is advanced through the soil strata. The soil classification data make it possible to select porous soil units that are most likely to yield useful fluid samples.

2 Equipment Description

General

The MPS consists of three major items: probe, umbilical cable, and auxiliary components. The probe consists of a soil strength sensor system (cone tip and friction sleeve equipped with strain gages) followed by vertically stacked modules. The stacked modules are the critical components of the MPS, as each module contains a sampling port which is independently operated from the surface. Figure 1 is a photograph of the MPS system.

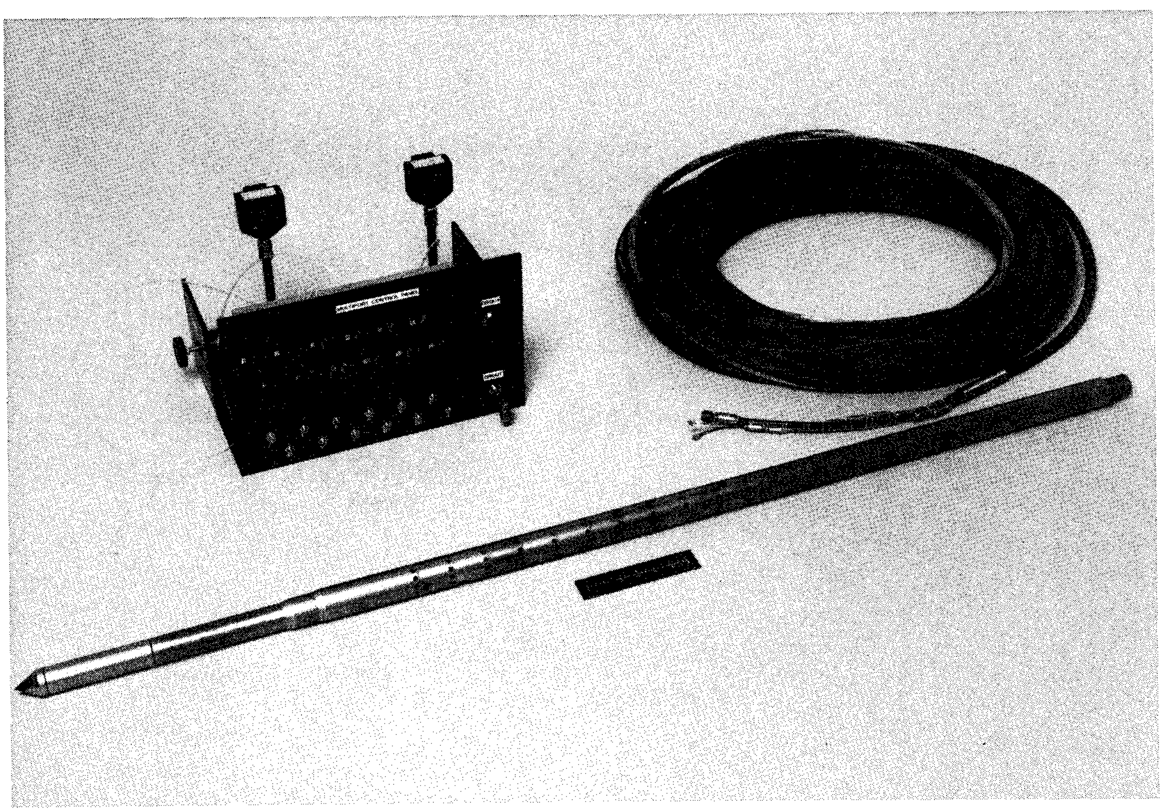


Figure 1. Multiport Sampler (MPS) system showing a six-port control console in the upper left, the umbilical cable in the upper right, and the probe with sampling modules installed at the bottom

The umbilical cable connects the probe to the surface (above ground) control and sample collection/analysis unit and contains up to 12 tubes each of which terminate at a separate sampling module. In addition, the cable contains the integral grouting tube and the electrical wires for the strain gages in the cone tip and sleeve (the electric cone) and Thermal Desorption Module (TDM).

Auxiliary components include the surface equipment required to operate the sampling modules and for sample or data collection. Such equipment includes the compressed air and vacuum sources, the valve control console, and the electric cone signal conditioning and data collection hardware and software. The TDM with its controller and the grouting equipment are also included as auxiliary items.

Component Descriptions

Probe

The MPS probe contains up to 12 sampling modules and is designed for attachment to a standard electric cone penetrometer.

Electric cone. The electric cone penetrometer contains a cone tip and friction sleeve section that provide the probe with the means for determining subsurface soil type. The cone tip and friction sleeve house separate electromechanical, strain-gaged elements. The elements respond independently to penetration resistance (measured by the cone tip) and frictional forces along the external surface of the probe (measured by the friction sleeve). These measurements constitute the typical electrical cone penetrometer probe data which are used for soil stratigraphy identification and subsequent classification. Typically, the two elements sense changes in the soil type as the probe is pushed to depth. The electro-mechanical responses are translated into Soil Classification Numbers (SCN) through empirical relationships via the computerized data collection system. Each SCN represents a soil type that corresponds to elementary soil classification descriptions (sand, silt, clay, etc.). The two elements (cone tip and friction sleeve) respond independently, but the combined response contributes to the development of the SCN. The reader is referred to Olsen and Malone (1988) and Olsen (1988) for a detailed explanation of the SCN.

Sampling modules. The port of each sampling module is independently opened to allow fluids (soil pore gas or liquids) to enter the module at any designated depth during the penetrometer push. Figures 2 and 3 indicate the top plan and sectional views, respectively. All sampling module parts are fabricated from D-2 steel and vacuum heat treated to minimize abrasion from soils. The parts of the sampling module are numbered in Figures 2 and 3 and described in the following text.

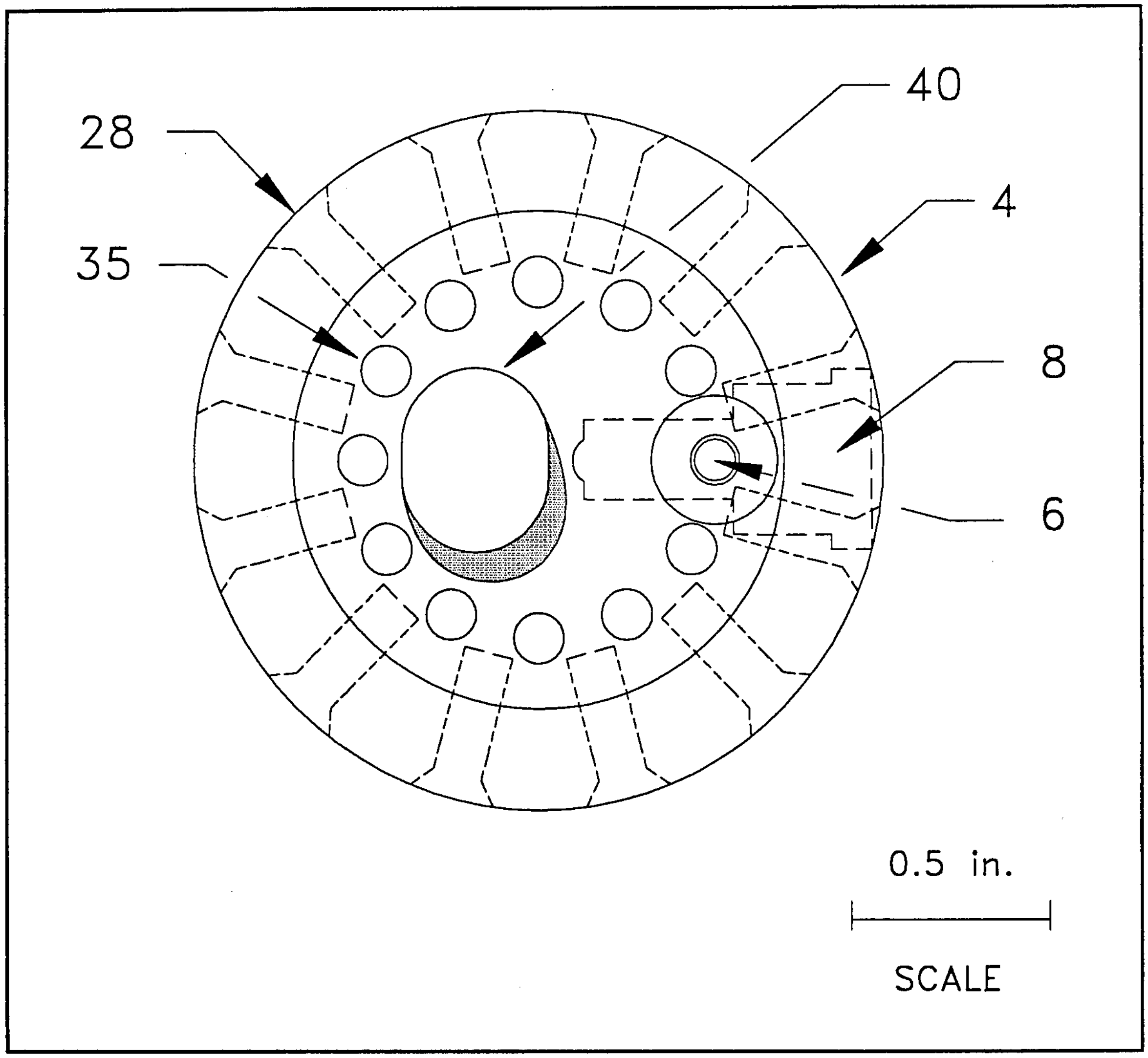


Figure 2. Plan view of the MPS module showing the positions of the holes for the vacuum/pressure lines for each port and the central opening for the grout tube and the electric cone instrumentation wires. The numbers are identified in the text

Item	Description
4	Steel housing
6	Sampling cavity
8	Transverse opening
10	Threaded insert (port)
10a	Inner lip and o-ring
12	Piston
12a	Piston tip
14	0.125-in.-diam nylon tubing/contaminant trap
28	Module connection screw holes
34	O-ring
35	0.125-in.-diam nylon tube passageway
40	Grout tube and electrical wire passageway

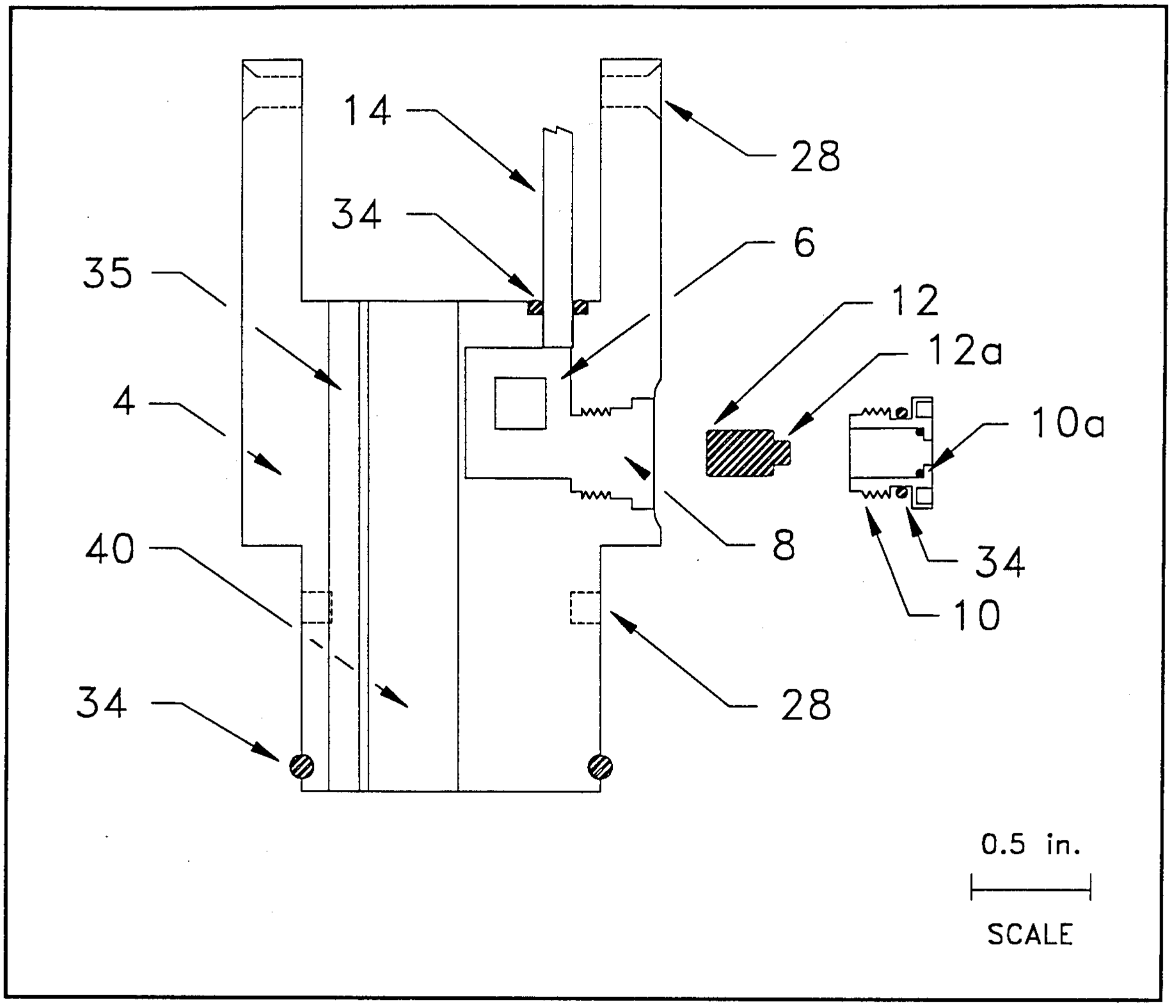


Figure 3. Section view of the MPS module showing the internal configuration of the module. The numbers are identified in the text

The sampling module is a 1.75-in.-diam steel housing (4) containing a sampling cavity (6). The cavity includes a transverse passage or opening (8) which extends to the exterior of the module. An insert (10) is threaded into the housing within the transverse opening (8). The insert (also referred to as the port) contains a cylindrical chamber configured to receive a piston (12) which slides outward to close the port (Figure 4a) or slides inward to open the port (Figure 4b). Movement of the piston is controlled by varying the fluid pressure within the sampling cavity. The fluid (clean compressed air or an inert gas) is supplied via the umbilical tubes. The insert (10) has an inner lip portion (10a) which prevents movement of the piston (12) outside of the opening (8) or beyond the exterior surface of the housing (4). When the piston is in the closed position, the piston tip (12a) is flush with the exterior surface of the housing preventing port contamination from soil and/or fluids. When sampling, a sample is drawn through the port (10), into the sampling cavity (6), and either into 0.125-in.-diam nylon tubing (14) to the surface for

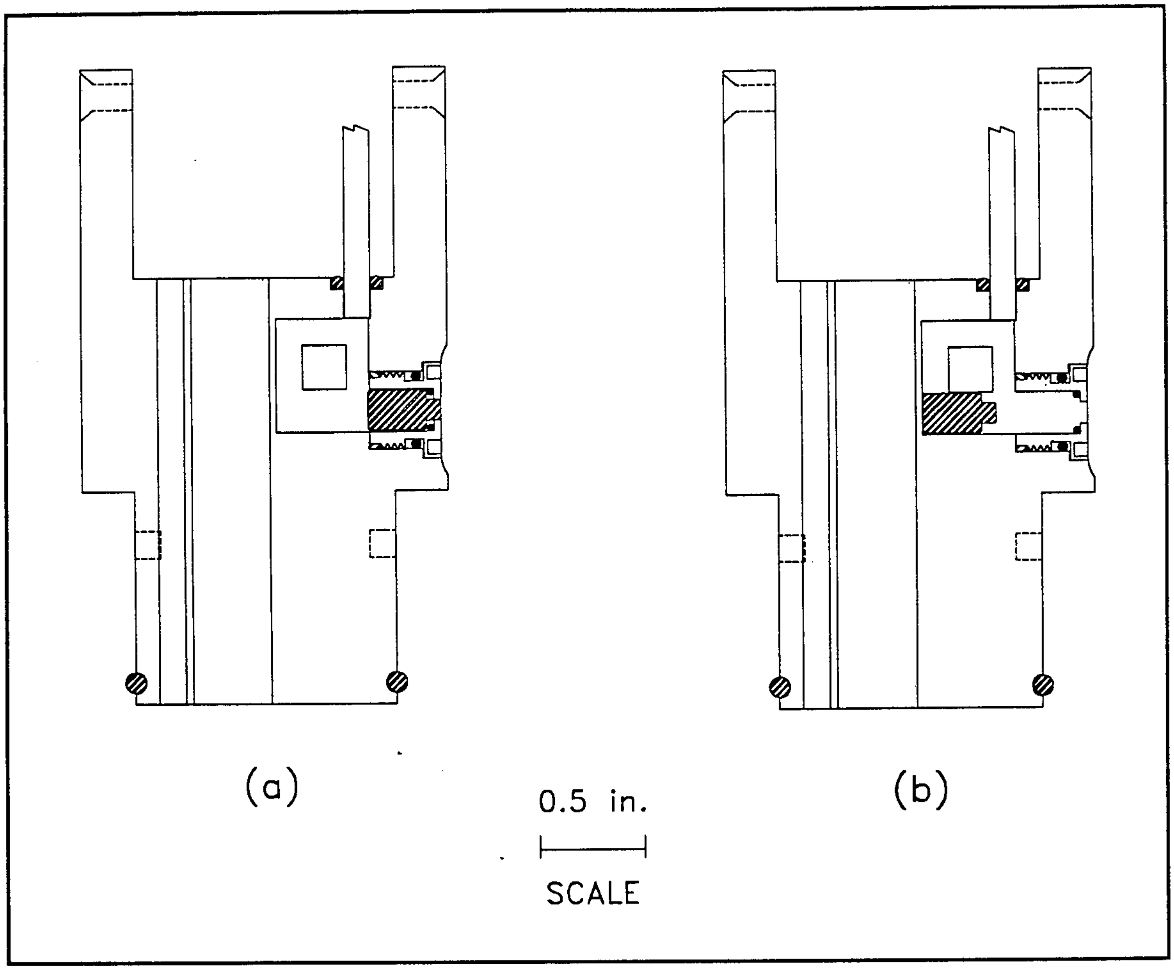


Figure 4. Crosssection of the MPS module

direct analysis or into a contaminant trap (14) for a post analysis after the MPS is withdrawn.

Multiple modules are vertically stacked together such that the ports spiral counterclockwise (Figure 5). The ports are offset to allow connection of each tube in the umbilical to its associated port. Such an arrangement provides an assembly capable of successively or simultaneously taking multiple samples at different depths with only a single push or insertion of the penetrometer into the ground.

Umbilical cable

The umbilical cable (Figure 6) connects the MPS sampling modules to the surface (aboveground) equipment. It consists of ten 0.125-in.-diam nylon tubes concentrically bundled around one 0.375-in.-diam grout delivery tube. Two four-conductor electrical wires that attach to the electric cone tip and friction sleeve and two Teflon-coated 14-gauge copper wires that attach to the

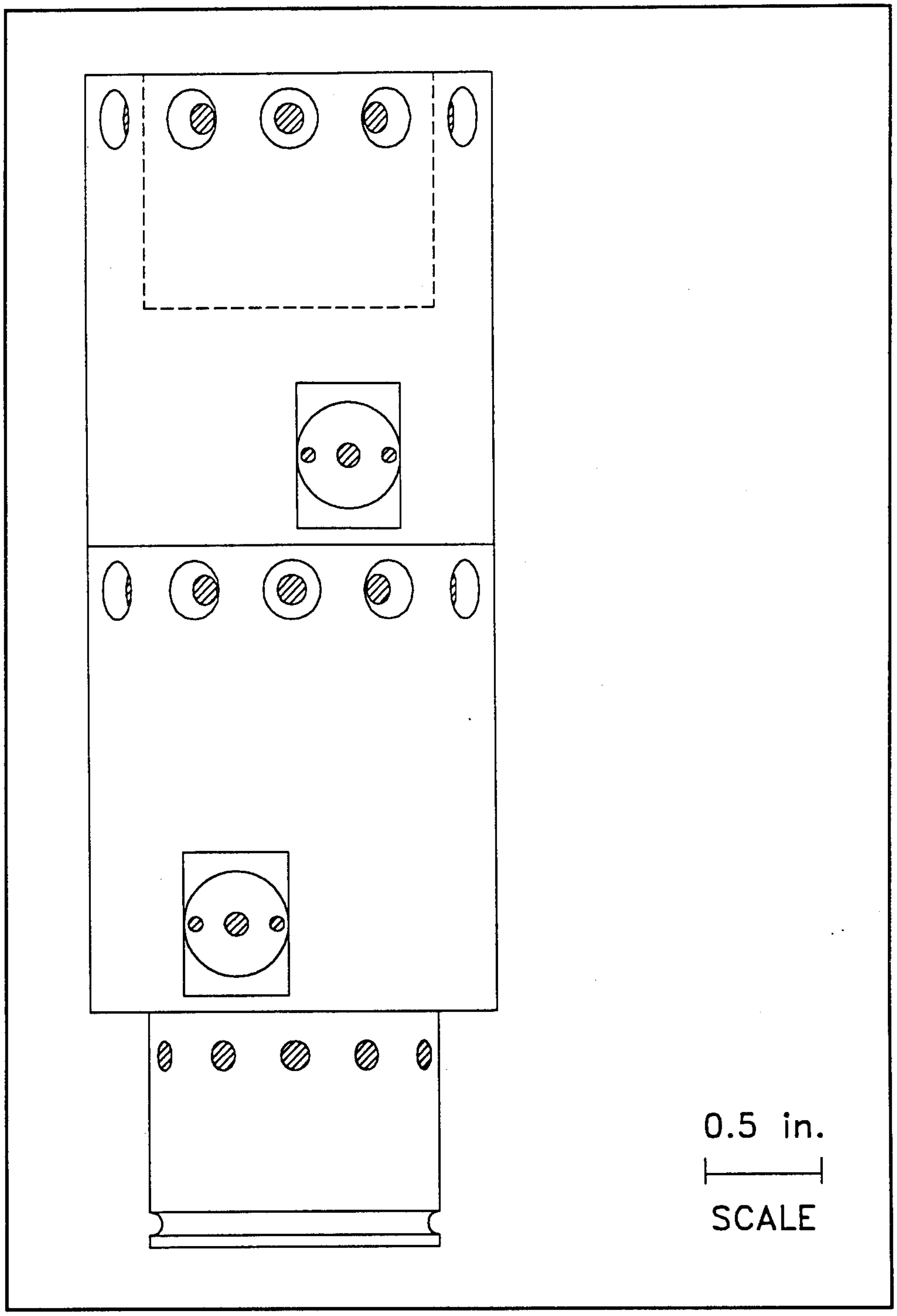


Figure 5. Sketch of exterior of stacked modules showing the position of successive ports

TDM are also incorporated into the umbilical cable. Although the MPS probe is designed to accommodate up to 12 modules, currently only 10 modules are used. An umbilical containing 10 tubes is more easily pulled through the pushpipe during field operations.

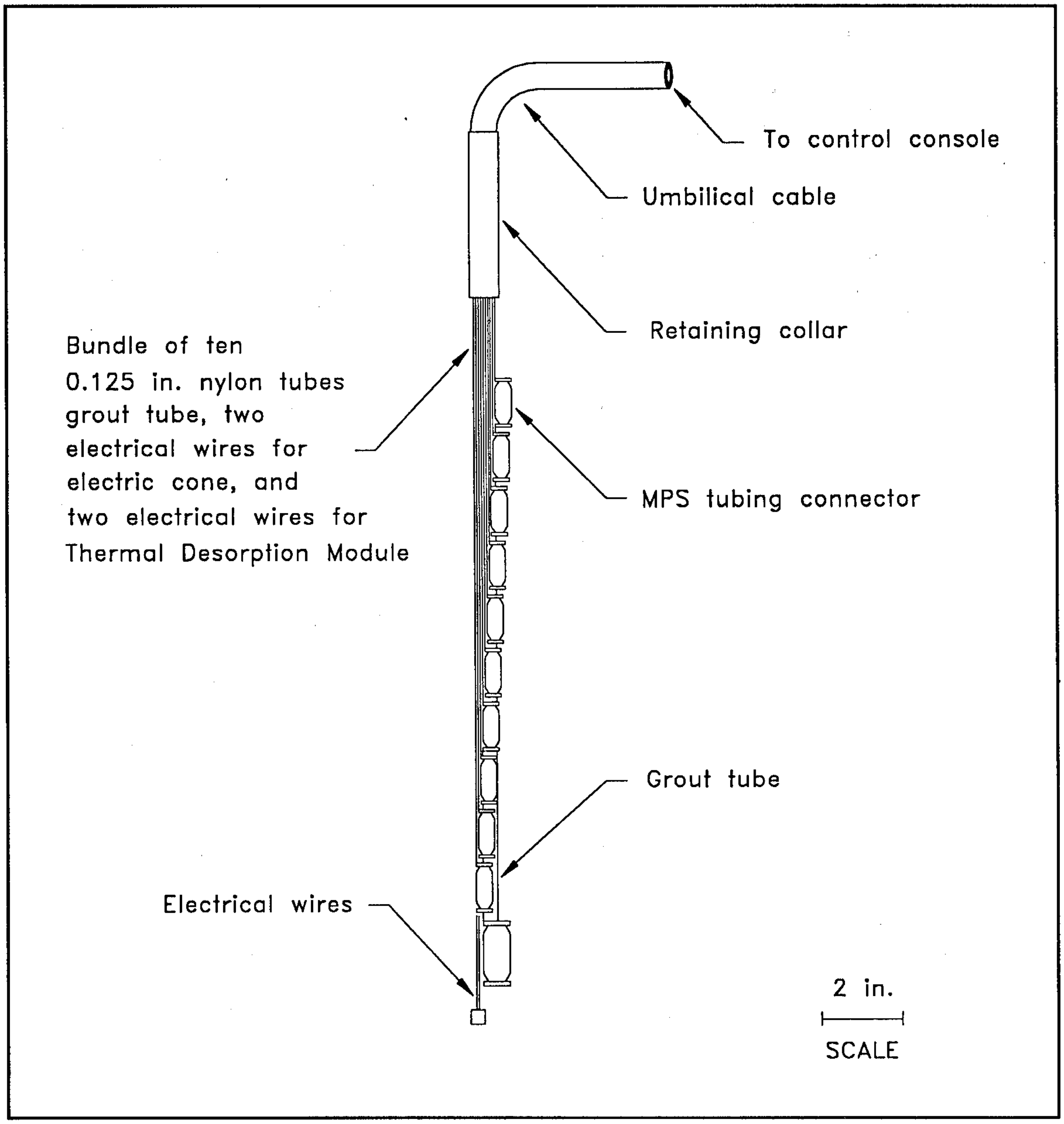


Figure 6. Schematic drawing of the umbilical cable showing the layout of the tubing connectors for connection to the MPS sampling modules

The outside sheath of the umbilical is composed of a heat-shrink neoprene tube. Total length of the umbilical is approximately 150 ft, with allowance for terminal connections. Overall outside diameter of the umbilical is approximately 0.75 in. Each tube terminates into a straight-line o-ring-sealed mechanical connector, enabling easier assembly MPS and umbilical.

Adapters

Four adapters are necessary for integration of the electric cone, MPS sampling modules, umbilical cable, and pushpipe. Figure 7 shows the individual adapters and Figure 8 shows the location of each adapter when the MPS probe is assembled. Adapter A connects the electric cone threaded joint with the screw connection on module 1. Adapter B connects the screw connection on module 10 (or 12) with the threaded connection of the tube housing. The tube housing is required to protect the tube and electrical connections between the MPS probe and the umbilical. Adapter C threads into the tube housing and adapter D. Adapter C is securely attached to the retaining metal collar of the umbilical cable with set screws and provides the final water-tight o-ring seal between the MPS and the pushpipes. Adapter D matches adapter C with the tapered thread of the pushpipe. The threads on the pushpipe are proprietary (Hogentogler Corp.™), thus requiring an adapter to integrate the MPS with the pushpipe.

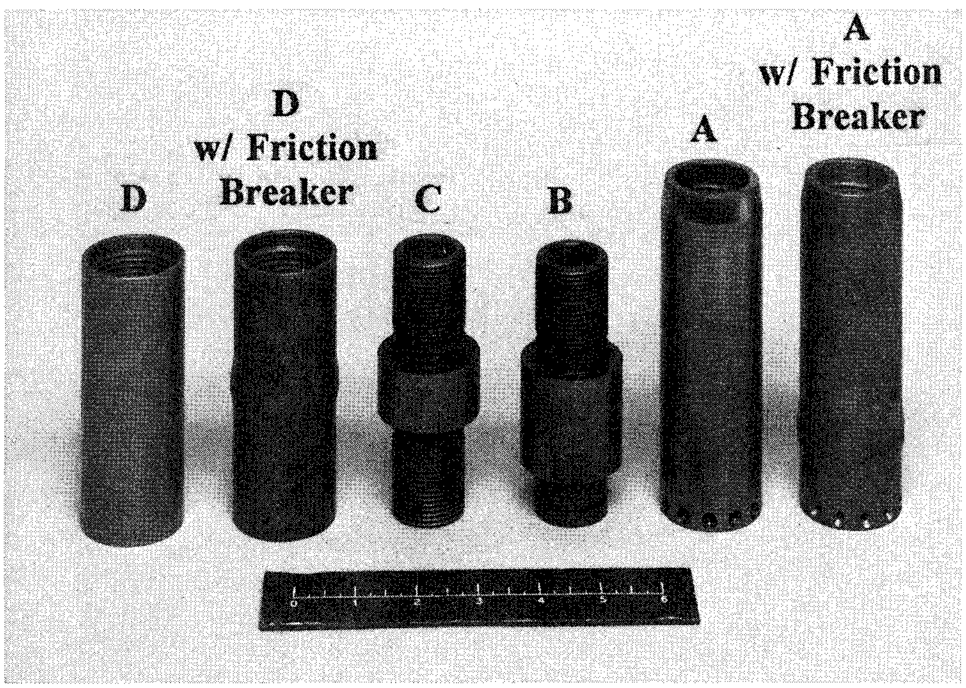


Figure 7. Adapters required to integrate the MPS probe, umbilical cable, and pushpipe

Adapters A and D come in two different configurations, with and without a friction breaker. The friction breaker is an enlarged section in the diameter of the adapter that enables deeper penetration by effectively reducing soil friction immediately circumferential to the pushpipe. Friction breakers are installed prior to operation in difficult situations, i.e., adverse soil conditions or excessive depths. The friction breaker adapters are shown in Figure 7.

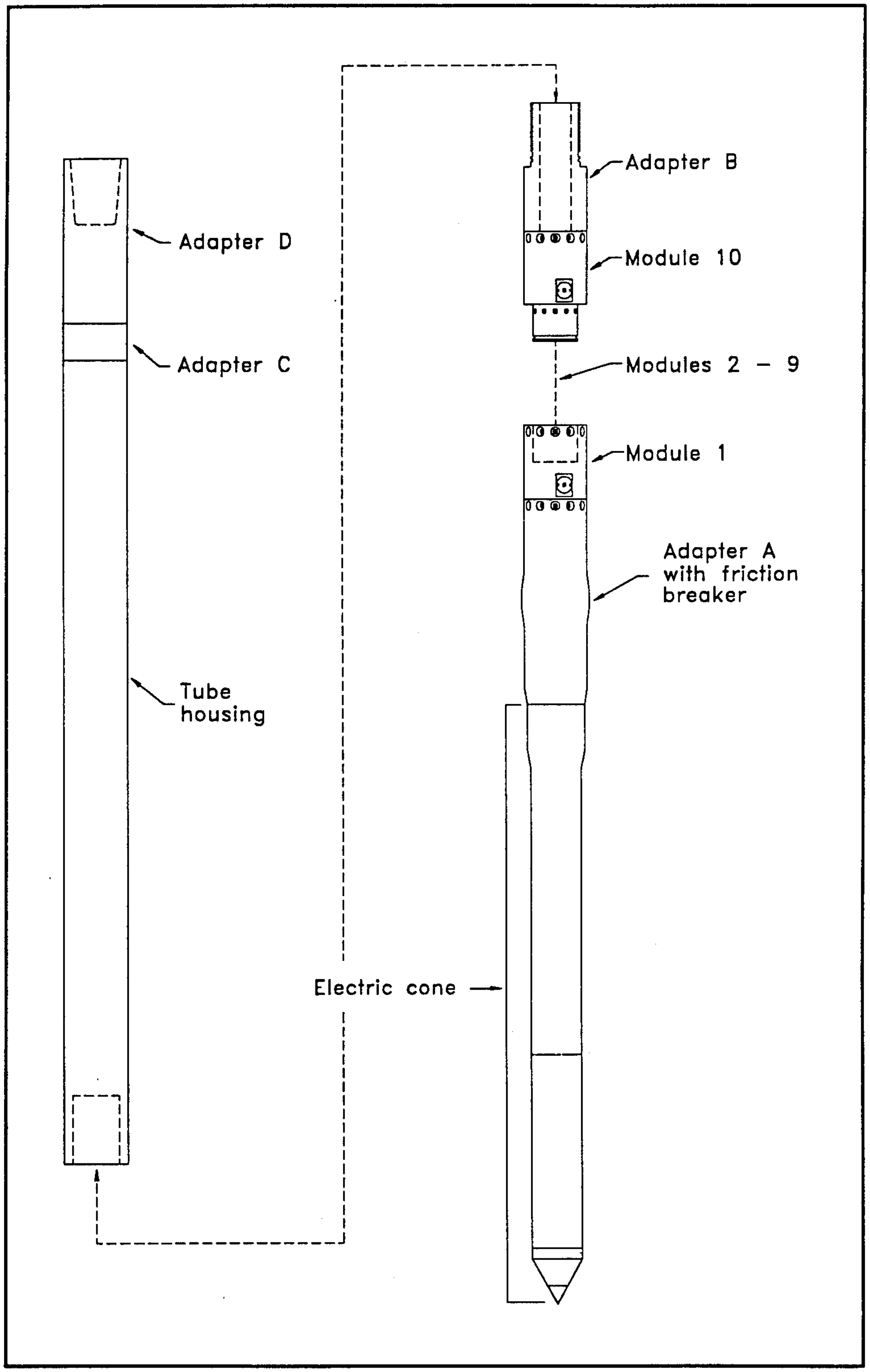


Figure 8. **Schematic drawing showing the location of each adapter in the pushpipe**

Control console

The control console provides the capability for independent operation of each sampling module. Figure 9 shows a schematic drawing of the control console valving. The tubes from the umbilical cable attach to the console at point B. Instrumentation for direct sample analysis or a vacuum source for alternate sampling requirements is connected at point A. An ITMS has been used for direct analysis of contaminated soil pore vapor. Each pair of three-way valves control sampling and airflow monitoring of each MPS sampling module. A nonbleeding pressure regulator provides pressure control and a digital mass flowmeter allows the airflow within each tube to be monitored. A compressed gas (nitrogen) cylinder is typically connected to the pressure regulator and a small portable vacuum pump is used as an alternate vacuum source.

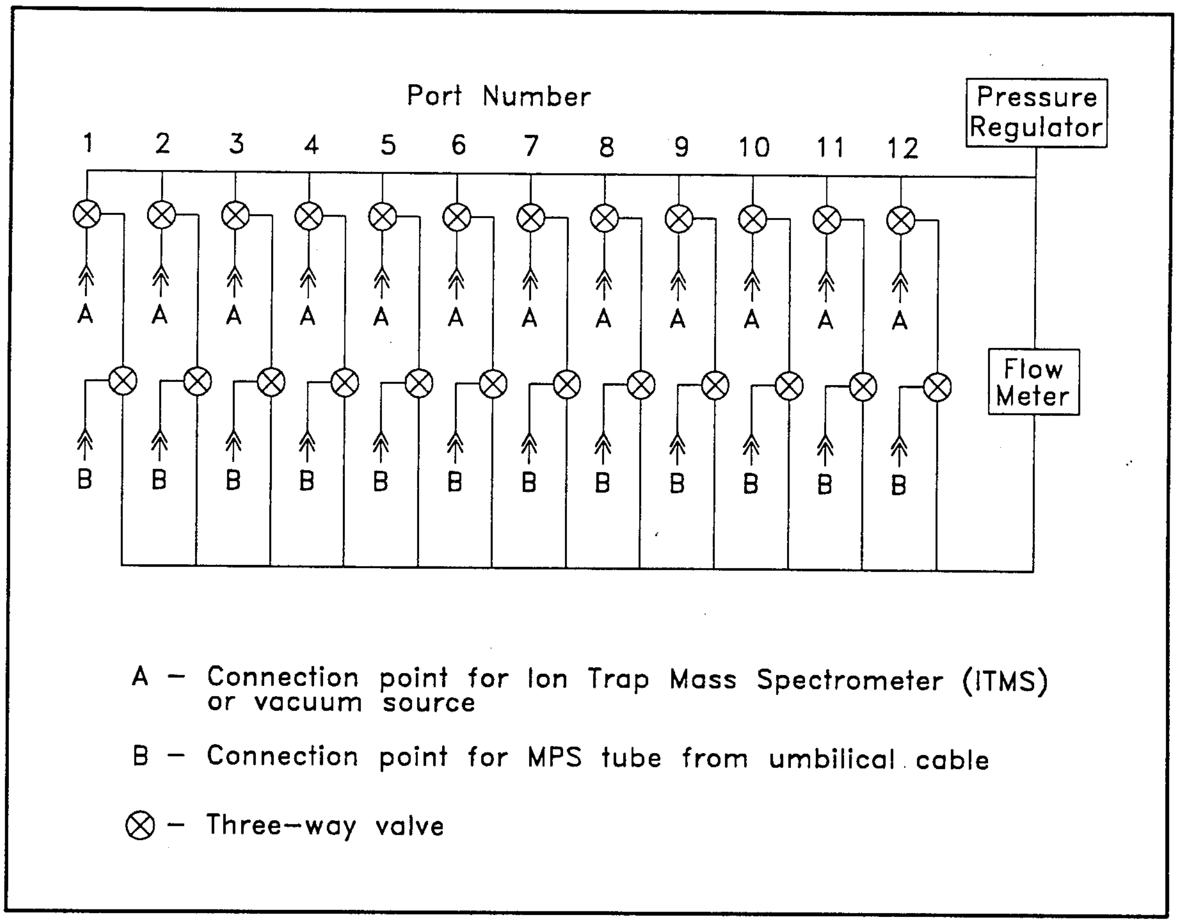


Figure 9. Schematic of the valving system used in a 12-port control console

The console is constructed of anodized aluminum to minimize weight and provide maximum resistance to corrosion, and its small size allows for field portability. O-ring-sealing quick-disconnect connectors are used for

connecting external air pressure and/or vacuum sources, instrumentation, and grout tubing.

Auxiliary Equipment

Thermal desorption module (TDM)

The TDM, when attached to the MPS probe, is housed in the space normally assigned to modules 1 and 2. These modules are closest to the electric cone and deeper than any other MPS sampling module during a penetration event. Figure 10 shows a schematic drawing of the TDM.

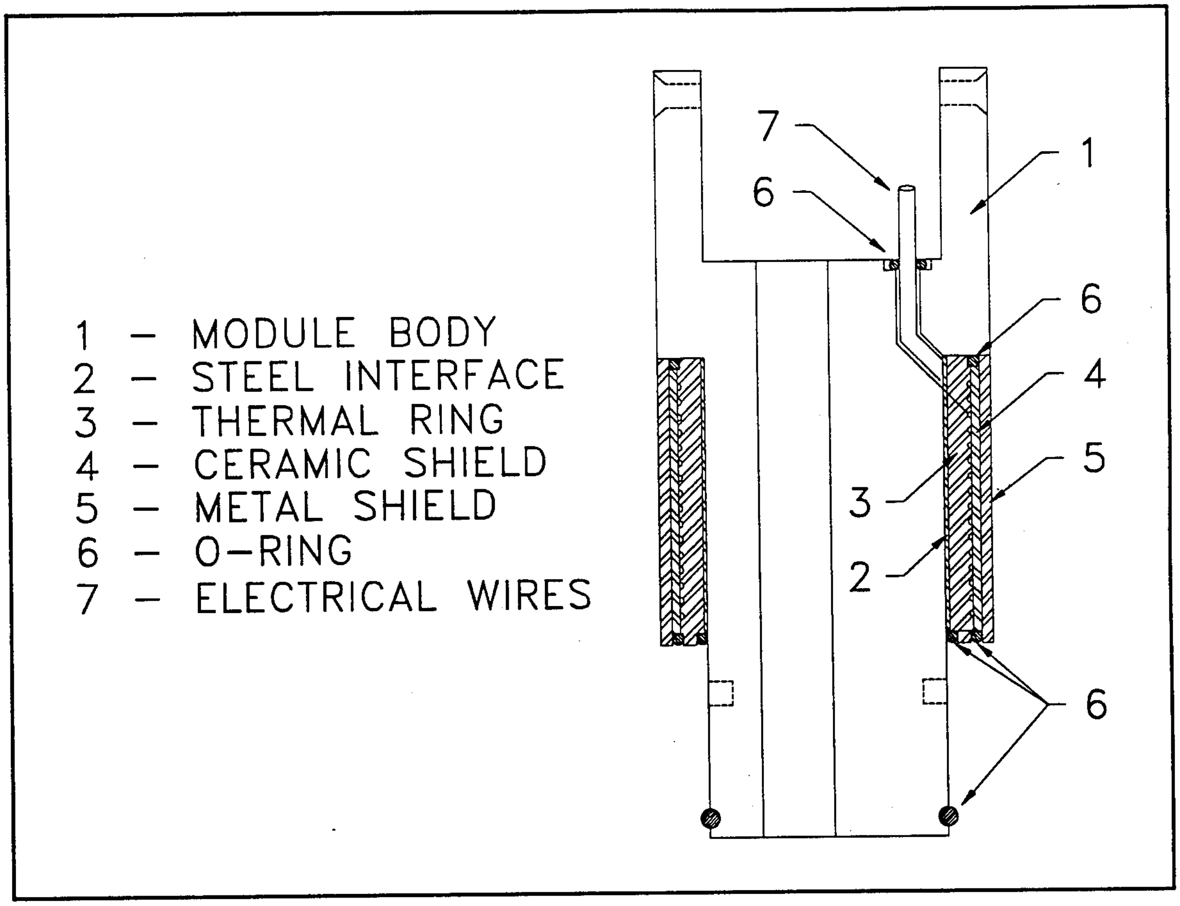


Figure 10. Schematic drawing of the Thermal Desorption Module

The TDM has the same basic configuration as the MPS sampling modules. The steel module body (1) holds a ceramic thermal ring (3) that is wrapped with a high-resistivity platinum wire (heating element). The wire is held in place by a heat-conductive ceramic shield (4). The thermal ring and ceramic shield are protected from the soil by an outer metal shield (5). The ceramic components of the TDM are protected from bending stresses by a steel

interface (2). The heating element is protected from water intrusion by o-rings (6).

At any given soil penetration depth, an electric current is passed through Teflon-coated wires that are located in the umbilical cable and connect to the heating element (platinum wire) of the TDM. The electric current passing through the heating element increases the temperature of the outer metal shield and surrounding soil to a maximum temperature of approximately 200 °F. As the soil heats up, volatilization of soil contaminants is enhanced. Sampling modules of the MPS are then opened to acquire vapor from the contaminated soil.

Compressed air supply

Compressed air is used in the MPS probe to ensure that the module ports are held shut during the penetration. At the target depth, the compressed air pressure is relieved, and a vacuum is applied to retract the piston into its sampling position. Noncontaminated air (i.e., pure nitrogen) is used during contaminant sampling.

Cleaning system

The main component of the MPS probe cleaning system is an ultrasonic cleaner. The cleaner is of sufficient length to immerse either the disassembled MPS modules or the assembled modules after their disconnection from the umbilical cable and electric cone. Other utensils (squirt bottles filled with methyl alcohol, Q-tips, and tweezers) are used for detail cleaning of the modules and ports prior to and after sonic cleaning.

The cleaning fluid may be distilled water, organic solvents, or a mixture of distilled water and solvents. Methyl alcohol is a useful solvent which is soluble in water or can be used in an undiluted form and is available in a highly pure form. Other solvents (i.e., ethyl alcohol, acetone, etc.) may also be used. In all cases, precautions are needed to prevent undue personnel exposure and accidental ignition. No cleaning agents containing chlorinated hydrocarbons or other target contaminants may be used due to the possibility of contaminating the sampler prior to sample collection.

3 Equipment Operation and Maintenance

Component Assembly

Modules

The accessories needed to assemble the individual modules are shown in Figure 11. The 0.125-in.-diam tubing connector (a) is used to connect the umbilical tubing to the MPS sampler module tubing. The grout tube connector (b) is used to connect the umbilical grout tube to the MPS grout tube. A special two-pronged tool (c) is used to remove the threaded insert (port). A tubing cutter (d) is used to cut the tubing at a right angle to ensure proper connections. A 0.078-in. Allen wrench (e) is used to install and remove the 0.375-in.-long 5-40 hardened flathead cap screws (f) that hold the MPS together. O-rings (g) are used for pressure and water seals through out the MPS (sizes from right to left are: 5-178, 2-005, 2-010, and 2-024).

Prior to their assembly, the individual modules are thoroughly cleaned using organic solvents or water in the ultrasonic cleaner. Each o-ring is lubricated with an inert silicone lubricant and installed in the locations previously noted (Figure 3). Care must be taken not to nick the o-ring material or allow any debris to remain in the o-ring grooves, since these would be potential spots for pressure loss and leakage. The piston is inserted into the threaded port, and the piston-port assembly is inserted into the module. The special tightening tool (Part c, Figure 11) is used to firmly tighten and seat the port.

Pressure check

A piece of 0.125-in.-diam nylon tubing is inserted into the top of the sampling cavity by firmly pushing it past the o-ring until it seats. The nylon tubing must be cut squarely (Part d, Figure 11) to prevent tip burrs and uneven edges from interfering with the o-ring seal.

Compressed air is used to pressurize the nylon tube and check the integrity of all o-ring seals and the sampling port piston. An approximate gage pressure of 50 psi is used initially to verify all seals; a higher pressure could cause

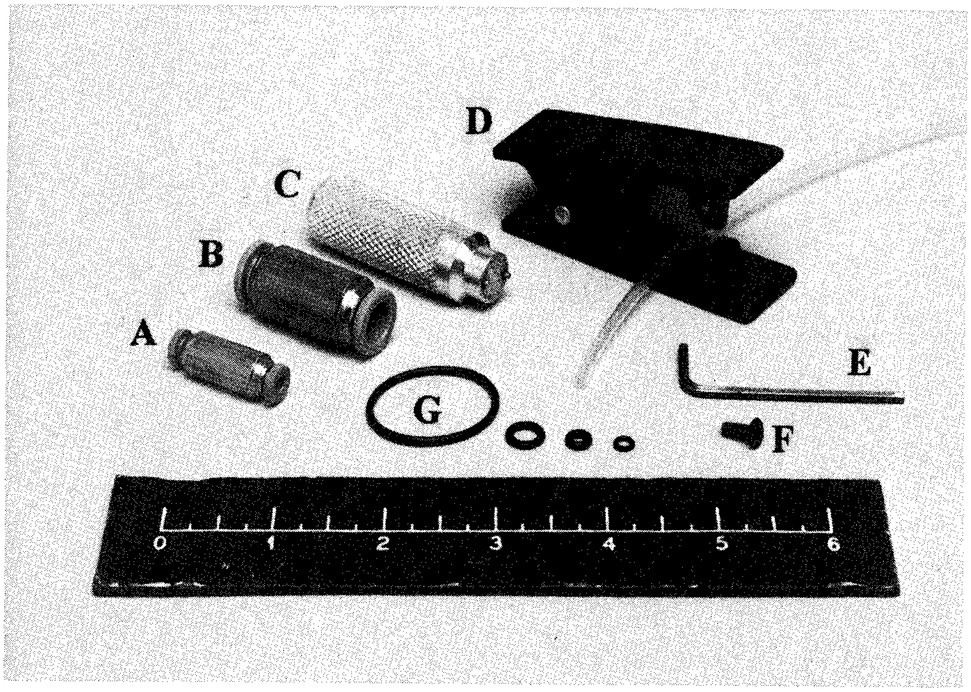


Figure 11. Components needed to assemble the MPS

injury if tubing and parts are not secure. The piston should be in the closed position, and no evidence of pressure leakage should be detected. Audible and visible (bubbles from drops of water over the port or any air flow as shown by a flow meter) leak detection methods may be used. A leaky piston or port will require investigation and correction prior to pushing the MPS probe. Once a leak-free system is achieved at 50 psi, the pressure is elevated to 125 to 150 psi (the pressure required to keep the ports closed during pushing) for the final leakage check.

Probe Assembly

Sequence

Figure 12 is a schematic drawing of the MPS probe showing the essential components required during the sequence of assembly. The assembly sequence is as follows:

a. Assemble the stacked modules.

b. Cut and install tubing into the modules.

c. Connect the electric cone and adapters A and B.

d. Connect the probe tubing to the umbilical tubing.

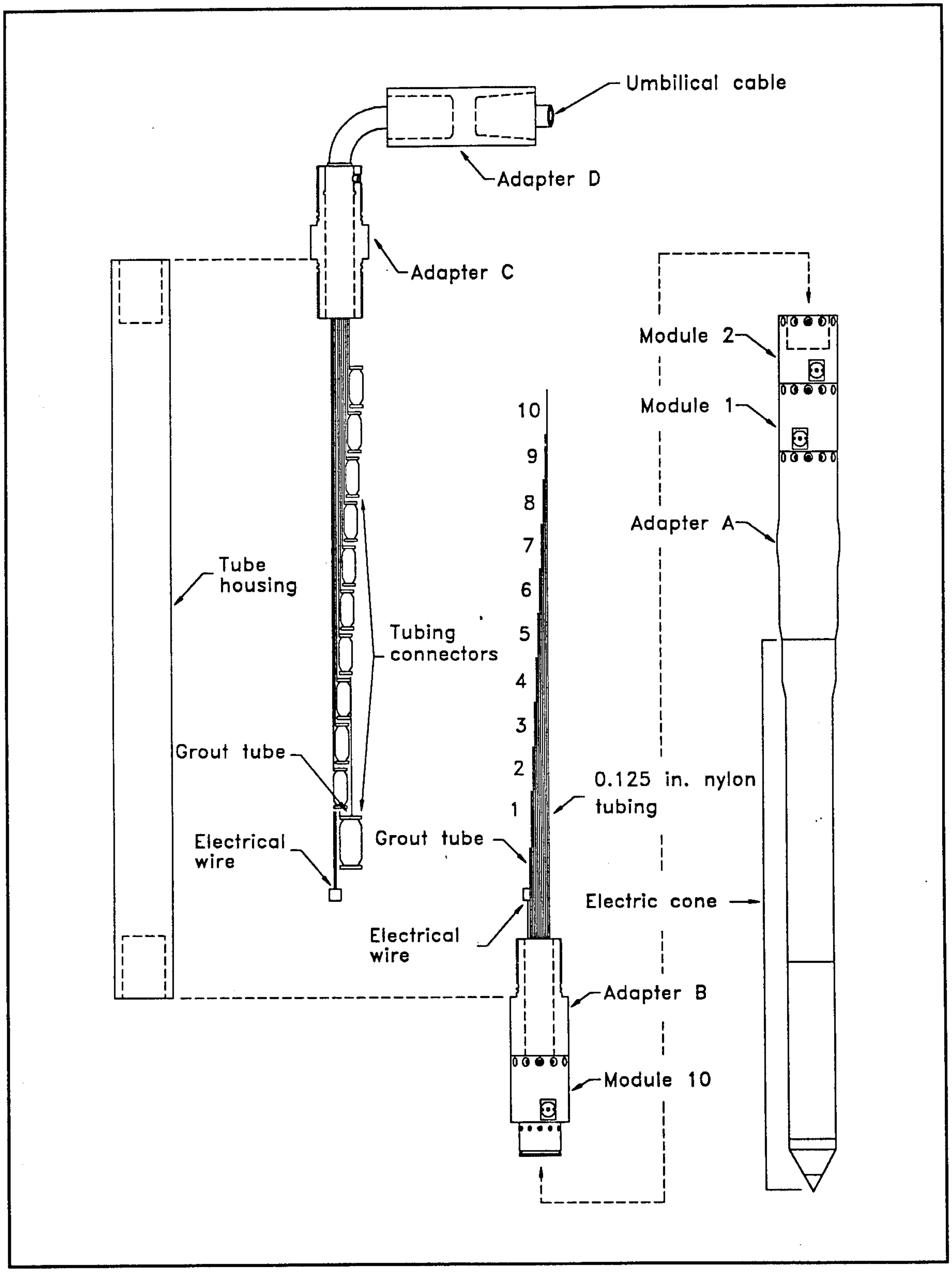


Figure 12. Schematic drawing of the MPS probe assembly

e. Connect the tube housing and adapter C.

After each module has been individually assembled and pressure checked, the modules are stacked by pressing and twisting until the bottom of the module above is firmly seated onto the top of the module below. During the stacking process, the positioning of the individual ports form a downward clockwise spiral pattern when viewed from above (Figure 5). The modules are aligned by various methods: aligning the attachment screw holes, sighting through the open tube passageways, or by inserting a piece of 0.125-in.-diam tubing through the modules. Any misalignment is readily apparent. The modules are then held in place by inserting one or two screws (Part f, Figure 11) into the attaching screw holes and hand-tightening. The beveled edges of the screw holes cause the 0.125-in.-diam nylon tubing o-ring to compress and align the two modules as the screws are tightened.

After all the modules have been connected by at least two screws per module, the MPS sampler module tubes are installed. Each tube is pushed through the appropriate 0.125-in. passageway and press-fitted into the top of the sampling cavity of the associated module. The longest tube extends down into module 1 (nearest the electric cone), and the shortest tube extends to the upper module 10. Figure 13 indicates the relative length of tubing required. The tubing lengths required for WES MPS probes are:

Tube Number	Length (in)
1	27.8
2	27.2
3	26.5
4	25.8
5	25.0
6	24.4
7	23.7
8	23.0
9	22.3
10	21.7

After the tubes have been cut and inserted, each one is checked for a proper o-ring seal by pressing and slightly twisting. The press-fit, o-ring seal, and air pressure hold each tube in place. The integrity of the seal may be ascertained by the hand pressure required to pull the tubing out of its o-ring seal. A spacer ring is then placed over the tubes onto the top of module 10. The spacer is used to seal the o-ring around the sampling tube attached to module 10 (adapter B cannot apply pressure over the entire o-ring to facilitate the seal).

Adapter A is threaded onto the electric cone, taking care not to twist the electrical wires of the electric cone. The electrical wires are pushed up through the grout tube passageway. The 0.375-in.-diam grout tube is then measured and cut. One method of preventing the grout tube from curling is to insert a 0.187-in.-diam wooden dowel inside the grout tubing and place the

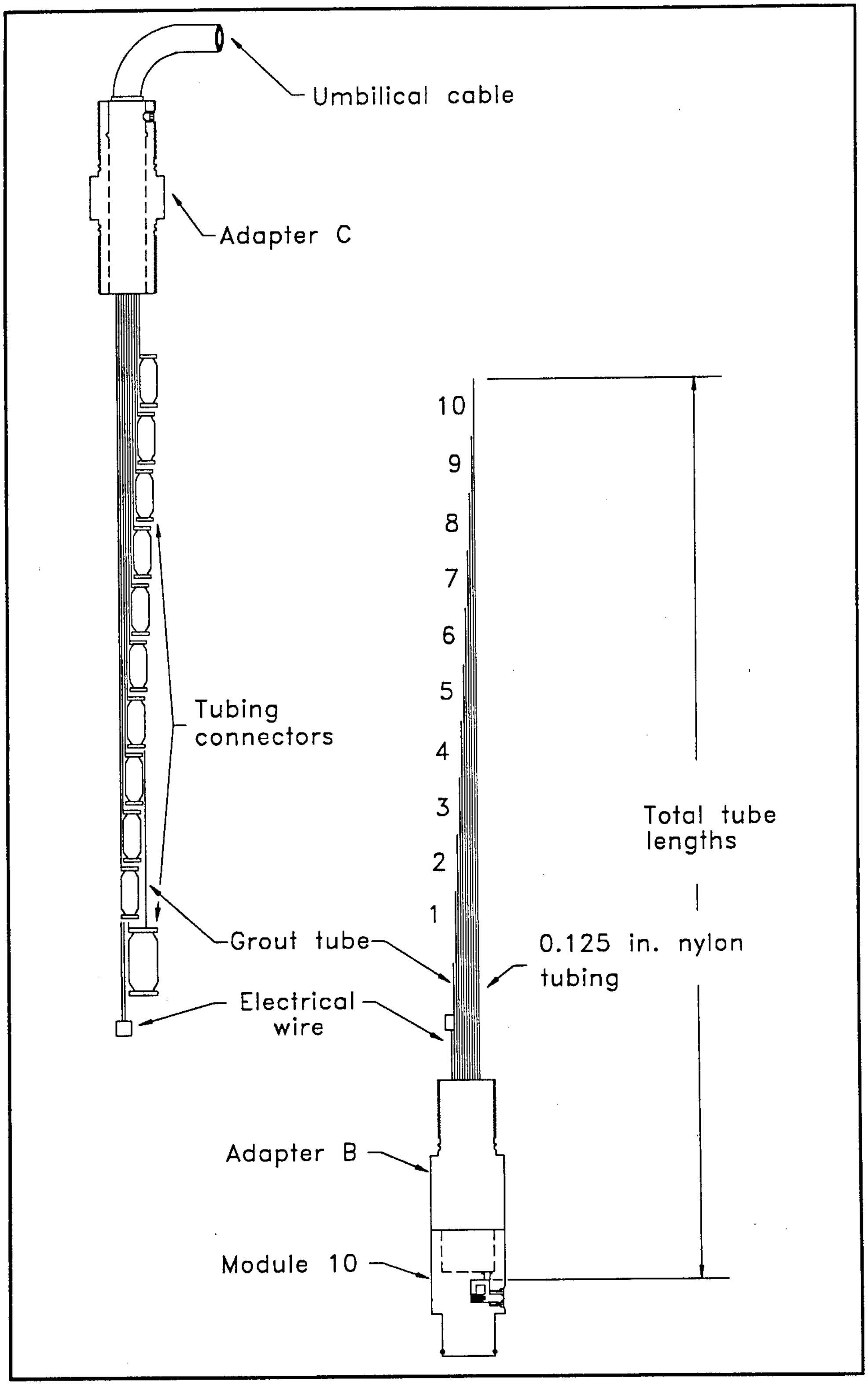


Figure 13. Schematic drawing showing the relative length of tubing that connects the MPS sampling modules with the umbilical cable

tube and dowel inside an oven for 0.5 hr at approximately 140 °F (do not heat the nylon tubing to a temperature greater than 200 °F). Usually the grout tube will straighten and is then ready for insertion into the MPS probe. The grout tube is carefully threaded through the grout tube passageway and connected. The assembled MPS sampling modules are mated with adapter A, the screw holes aligned, and the screws inserted and tightened. All remaining screws are then installed along the entire length of the probe and finger-tightened with an Allen wrench (or mechanical drill bit). After probe assembly is complete, all screws are tightened.

Final assembly and pressure check

The MPS probe is now completely assembled; but not yet connected to the umbilical cable. Adapter B is now carefully placed over the tubes and inserted into the top of module 10. Its connecting screws are installed and tightened.

First, adapter D, then adapter C, and finally the tube housing is slid over the tubes of the umbilical cable that connect to the MPS, past the metal collar, and onto the heat neoprene shrink tubing that covers the umbilical cable. Tubing connectors are placed on the nylon tubes and grout tube of the umbilical cable and arranged in a spiral fashion around the grout tube. Because tubing length dictates which tube is which, there is no need to mark the tubes of the umbilical cable. The umbilical cable is now ready to be connected to the MPS probe.

Care must be taken not to accidentally disconnect any of the tubes that are connected to the MPS sampling modules. The grout tube is connected first, followed by the tube for module 10, tube for module 9, etc. All electrical wires are connected last. The tubing lengths are observed as they are connected, and too-short or too-long lengths are corrected to ensure a properly spiraling tube bundle.

After the connections between the probe and umbilical cable are completed, the umbilical cable is connected to the control console and the tubing pressurized to approximately 50 psi. The valves are sequentially opened to allow each module to be pressurized. Observing the pressure gage on the console for any pressure drop and listening will determine if leaks are present. If a flowmeter is available, it can be used to determine if there is a leak. At this point, the modules are again individually checked for pressure leaks, and the piston is cycled open and closed. Any leakage should be investigated and corrected.

The control console and modules are then depressurized, and the tube housing is slid over the tube bundle and threaded onto adapter B. Adapter C is then slid down, threaded onto the tube housing, and secured to the metal collar by tightening the hex set screws. Finally, adapter D is threaded onto adapter C. The MPS probe assembly is now complete. The tubes connected to the control console are disconnected and taped to protect then from dirt,

wear and tear, and contamination while the pushpipes are threaded onto the umbilical cable. The pushpipes are threaded onto the umbilical cable only once and removed only after completion of the site investigation.

Probe Disassembly

Sequence

After sampling has been completed, the MPS probe is disassembled by reversing the sequence for assembly. The sequence is:

a. Disconnect adapter D from adapter C.

b. Loosen the hex set screws and disconnect adapter C from the tube housing.

c. The tube housing is unscrewed and slid onto the umbilical cable.

d. Disconnect the electrical connections, grout tube, and each MPS sampling module tube from the umbilical tubing.

e. Disconnect adapter A from module 1 and carefully unthread adapter A from the electric cone, ensuring that the electrical wiring does not twist.

f. Carefully disconnect the grout tube from the electric cone and remove it from the MPS sampling modules.

g. Finally, pull the electrical wire through the grout tube passageway and through adapter A.

Cleaning

The MPS is typically washed and/or wiped clean as it is pulled from the soil (the soil may or may not be contaminated and must be dealt with appropriately). The screw heads and the open ports are typically filled with soil and will require cleaning prior to their removal. Caution: attempting to unseat/remove the Allen screws prior to cleaning of soil from the screw heads may cause the screw head to strip. If the screws are removed, they are discarded. The o-rings are always removed, cleaned, and inspected before they are reused. The o-ring grooves are also cleaned.

Two stainless steel wire baskets are used to hold the parts from the MPS probe: one basket for the smaller parts (ports and pistons) and the other for the sampling modules (either assembled or disassembled). The MPS parts are placed in the baskets and then into the ultrasonic cleaner for approximately 0.5 to 1 hr. After cleaning, all parts are removed from the ultrasonic cleaner and the cleaning fluid placed in a container for disposal.

4 Field Operations and Tests

Integration with the SCAPS

The SCAPS is centered a cone penetrometer mounted in a uniquely engineered, 20-ton, all wheel-drive truck. The truck body is separated into two compartments: the hydraulic push area and the data acquisition area (Koester et al. 1994). These work spaces are designed to minimize exposure of the work crew to contaminants. The truck is fitted with a hydraulic power unit and controls for operation of the cone penetrometer apparatus. Figure 14 shows the SCAPS truck.

Threading the MPS probe umbilical

The threading procedure involves slipping the 39.4-in.-long pushpipe rod sections over the umbilical cable of the MPS probe. The number of pushpipe sections used varies with the maximum depth of the push. Umbilical cable slack is required to: store the pushpipe rod sections on the push area racks, route the terminal end of the umbilical cable through conduit inside the truck, and allow for safe handling during a penetration event. The total length of the umbilical cable must be approximately double the target depth.

The threading procedure requires the umbilical cable to be laid out straight, with the control console end directed away from the truck on relatively level ground. The control console tubing ends of the umbilical cable must be protected prior to the threading process by wrapping them with tape. The pushpipe rods are then slipped over the umbilical cable, male threaded end toward the truck, one rod section at a time, until the required number are in place. The rods are stacked sequentially on the rod racks in the truck push room. The wiring and tubing are then routed through the conduit into the data acquisition room and connected to the signal conditioning equipment and the control console, respectively.

Electric cone connection and calibration

A block diagram of the SCAPS instrumentation and support equipment applicable to the MPS system is shown in Figure 15. The diagram shows the

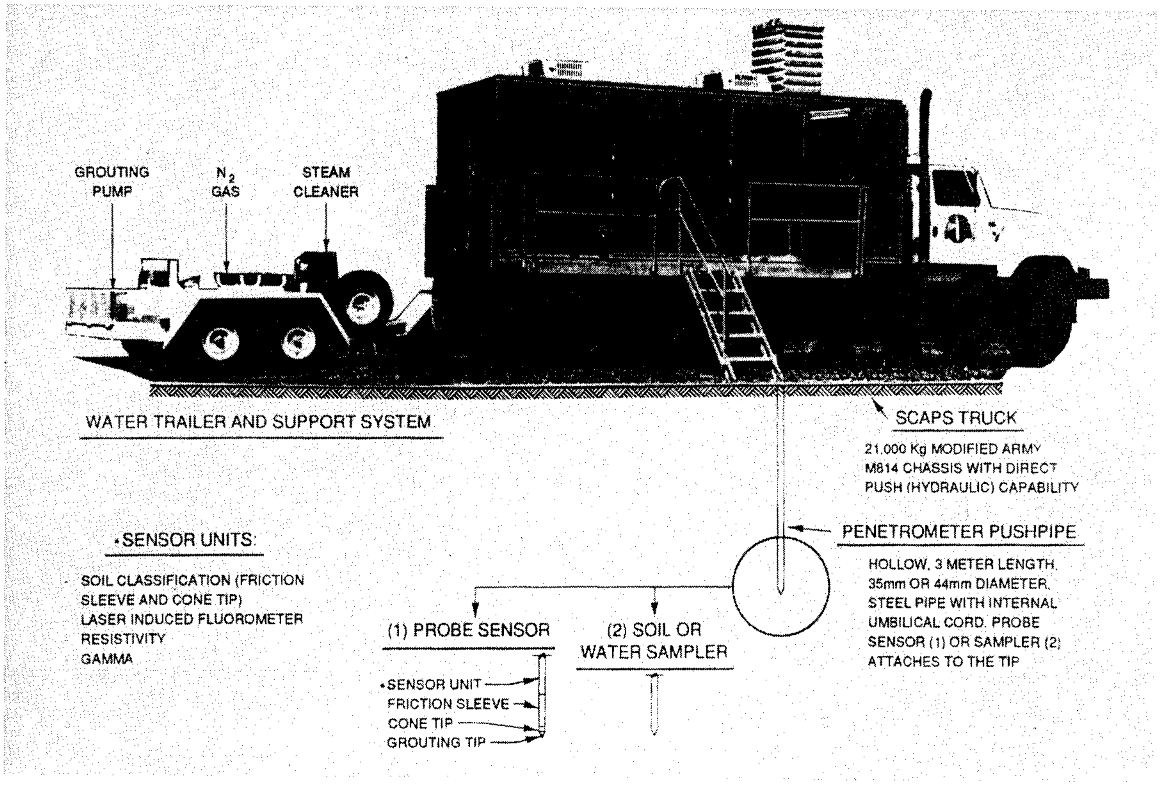


Figure 14. SCAPS truck showing the probe sensor configuration, sensor types, sampler types, sizes of penetrometer pushpipe, and support systems

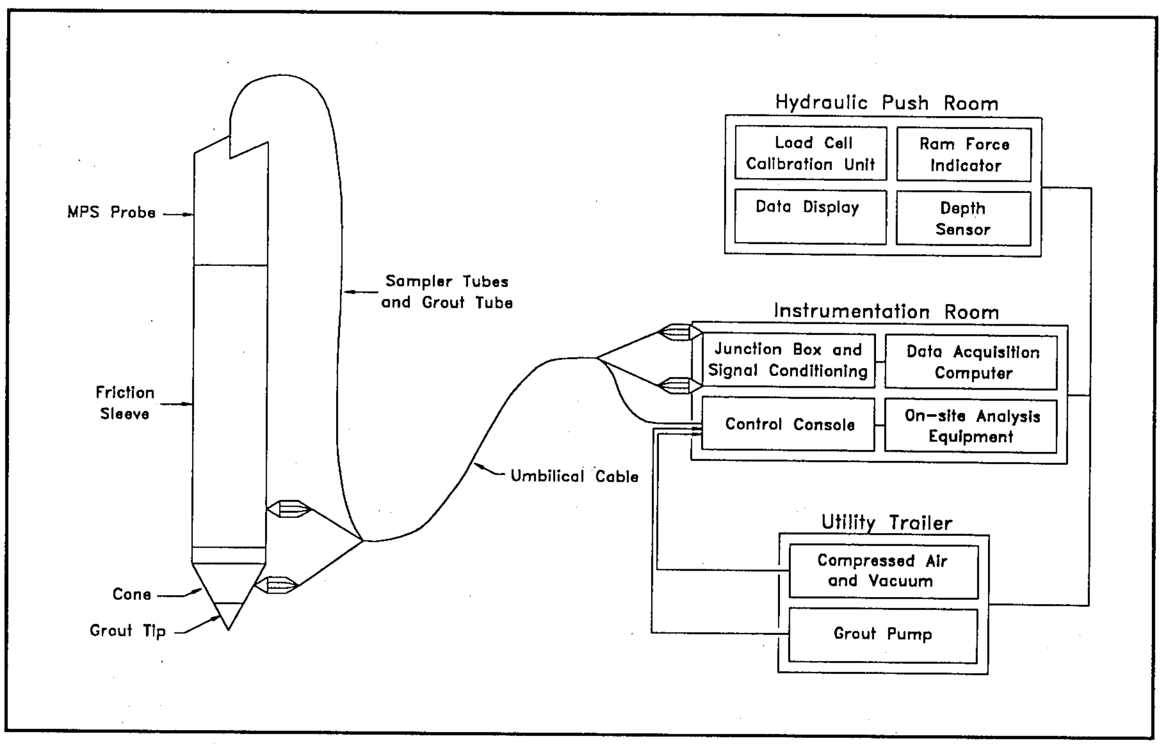


Figure 15. Block diagram of the SCAPS instrumentation applicable to the MPS system

relationship of the support components and the connections from the electric cone sensors to the strain gage read-out units (signal conditioning electronics) and computers. Figure 16 shows the electrical connections for the electric cone to the read-out units. Both the cone tip and friction sleeve, strain gage bridges have similar connections and are depicted by the same schematic diagram.

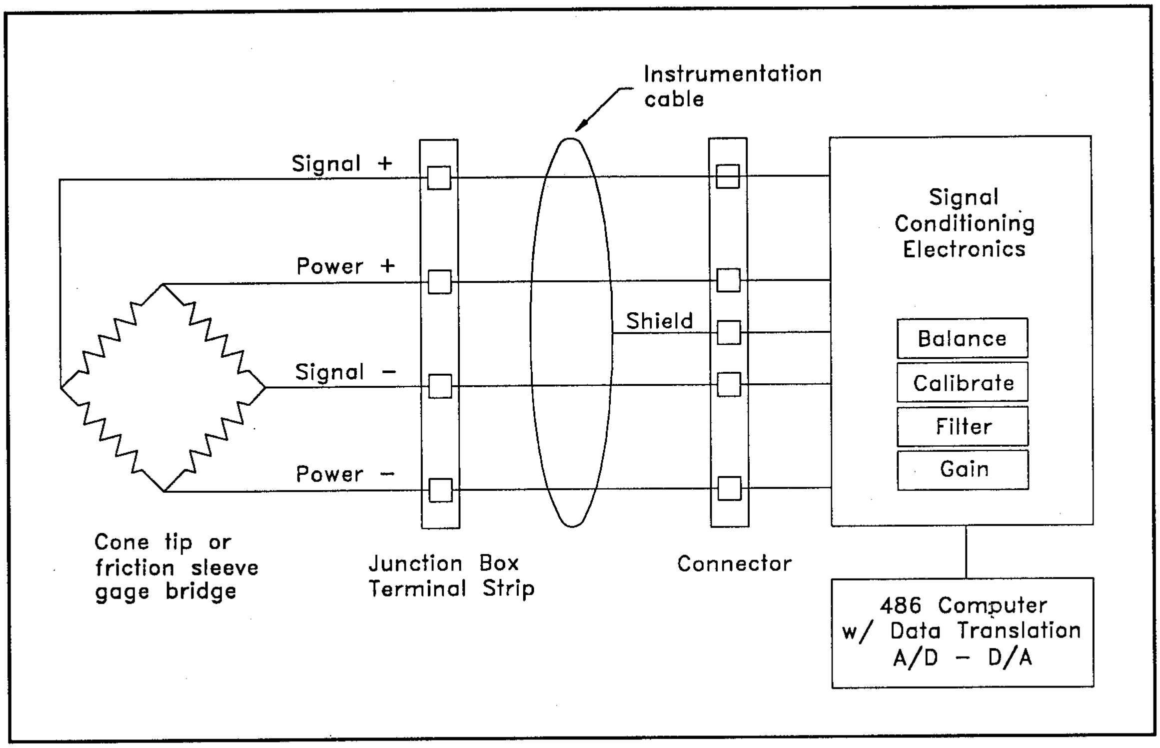


Figure 16. Schematic showing the electrical connections for the cone tip/friction sleeve to the signal conditioning electronics

The cone tip and friction sleeve of the electric cone are individually calibrated after the MPS probe is placed in the hydraulic ram of the SCAPS truck. Figure 17 shows the block diagram of the hydraulic ram and probe calibration components. For a detailed description of the calibration procedure the reader is referred to the SCAPS Operating Manual (Koester et al. 1994).

Sample and data collection

Sampling or monitoring equipment is connected to the control console for sample and data collection. By turning a valve on the control console, the piston sealing pressure can be removed from a selected port, allowing the port to be opened. A slight vacuum (-5 psi) is then applied to the piston/port to

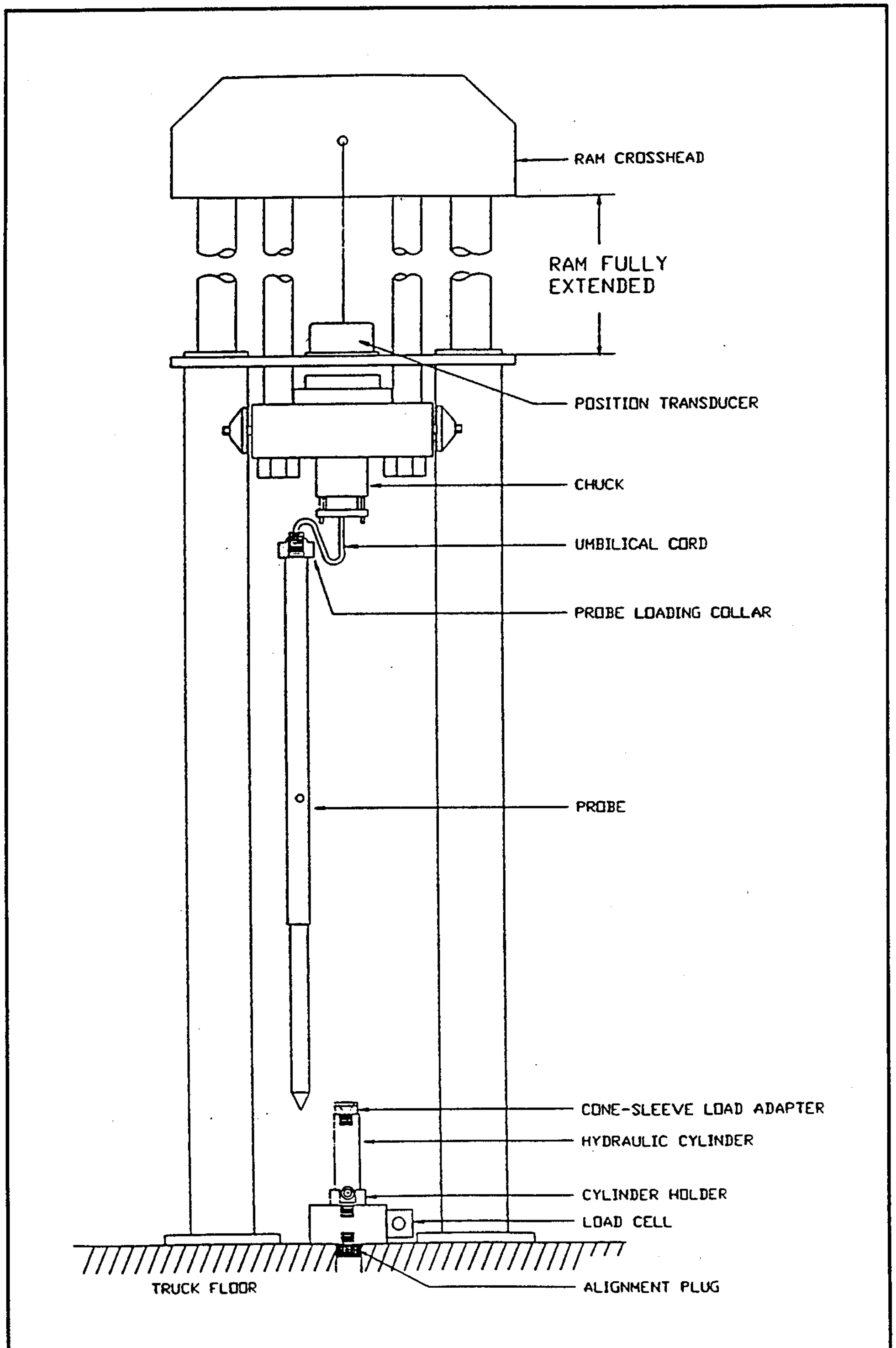


Figure 17. A block diagram showing the hydraulic ram and probe calibration components

open the port, and a sample is either drawn to the surface for analysis or into a contaminant trap for subsequent analysis. The same sampling or data collecting procedure can be repeated for other modules at the same depth or other selected sampling depths.

Operational Capability Tests

Waterways Experiment Station tests

The MPS probe was subjected to laboratory and field testing at WES to determine its structural integrity and operational capabilities. During the laboratory tests, the probe was hydraulically pushed into a large-scale stress chamber that simulated in situ soil pressures to depths of 250 ft. The probe was pushed during a 4-day test period to a simulated depth of 200 ft in sand. During each push sequence, the ports were tested for leaks and were opened under various soil and pressure conditions. The structural integrity of the probe was sufficient, but minor design changes in the port-piston configuration were made to improve their operability and to eliminate leakage of the pressurizing fluid.

A field test integrating the probe and the SCAPS truck was conducted at WES. A site containing homogeneous silt deposits was chosen, and the probe was hydraulically pushed to a 25-ft depth and retracted. During the push, the ports were held in the closed position under 125 psi of air pressure, and no pressure leakage was detected. The maximum ram force observed was 5.25 kips. At the termination depth, several ports were opened to ensure their operation under field conditions. No sampling was attempted.

Modifications to the standard calibration procedures and equipment were required before the cone tip and friction sleeve could be calibrated. Because of the probe's fully assembled length (66 in.), adapter D was unthreaded from adapter C to allow the probe to fit into the calibration load cell. Also, the loading collar was undersized and had to be refitted.

After completion of the field test and probe retraction, the probe was disconnected from the umbilical and returned to the laboratory for ultrasonic cleaning. During this process, several minor modifications to the disassembly and cleaning sequences were made. The procedures outlined in this report include the improved procedures.

Oak Ridge National Laboratory tests

The MPS probe was taken to the Oak Ridge National Laboratory (ORNL), Knoxville, TN, to perform laboratory evaluations of the probe's capability to retrieve samples from the vadose zone for qualitative and quantitative estimates of contaminant concentrations. A Direct Sampling ITMS and a Triple Sorbent Contaminant Trap (CT), both developed by ORNL, were integrated

with the MPS for these tests. The CT consists of a specially designed 0.125-in. stainless steel tube filled with chemical absorbents (such as activated carbon or chemically treated silica gel). The ORNL provided the contaminated soil test bed and laboratory equipment for analysis of contaminant concentrations.

The test bed consisted of a 12-in. stainless steel cylinder, 20-in. deep, filled with sand. The sand was given a 10-percent water content using a five parts per million (ppm) aqueous solution of trichloroethylene (TCE), causing the bulk concentration of TCE to be 0.5 ppm. Therefore, the vapor phase TCE concentration was between 0.5 and 5 ppm. The cylinder was filled with the sand and TCE mixture to within 2 in. of the top of the cylinder, covered, and allowed to equilibrate over a 24-hr period.

The probe was configured with three sampling modules that were labeled 1, 2, and 3. The ports were spaced 2 in. apart with port 1 being 10.5 in. from the MPS probe tip (port closest to the electric cone). Instrumentation for the electric cone and the grout tube were not connected during any of the tests. Compressed air, used to close the ports, was supplied from a high-pressure nitrogen gas bottle through a manifold configured from two 0.125-in. "T" fittings. A vacuum for opening the ports and sampling was supplied by the ITMS. The pressure/vacuum state of each port was controlled individually by a three-way valve. Ports 1 and 2 were fitted with a CT while port 3 was connected directly to the ITMS. Sampling flow rates were monitored using a mass flow meter.

The analytical instruments were calibrated prior to sampling of the TCE contaminant. The sampling procedure was:

a. Clean ambient air was drawn through the ports and tubing, using a vacuum pump internal to the ITMS. Analysis of the sampled air ensured that modules and tubing are free of contamination.

b. Port 1 was opened in the test bed and a sample was collected and analyzed using the ITMS. Two other samples were collected into CT's that were mounted inside the probe through ports 2 and 3; different lengths of time were used for the same flow rate. A tubing length of 5 ft was used for this test.

c. Samples were collected from port 3 for direct ITMS analysis and port 1 for a CT posttest contaminant analysis. A tubing length of 150 ft was used for this test.

During the first test (ambient air sampling), a trace of hydrocarbon contaminant was found in one port. However, the trace amount was not considered significant enough to prevent the ITMS from identifying the targeted contaminant, TCE.

The second set of tests (sampling of the vadose zone in the test bed) was conducted using tube lengths of approximately 5 ft. Both direct ITMS

measurements and posttest analyses (CT inside the probe) were performed. The following results were noted:

> Port 1 - TCE = 2.52 ppm, collected using a 2.2-ml/min mass flow rate (11 ml total volume drawn), data from a posttest analysis of the CT.
>
> Port 2 - TCE = 3.33 ppm, collected using a 2.2-ml/min mass flow rate (5.5-ml total volume drawn), data from a posttest analysis of the CT.
>
> Port 3 - TCE = 3.30 ppm, collected using a 30-ml/min mass flow rate, data from a direct ITMS analysis.

The third set of tests were conducted through approximately 150 ft of tubing. To assist in determination of flow rates versus contaminant concentration, TCE was sampled through the tubing connected to Tedlar^R gas bags having a TCE concentration of 0.2 ppm. The dead volume in the tubing was calculated to be approximately 200 ml and should have required 13 min for the contaminant to reach the ITMS at a sampling rate of 15 ml/min. In fact, only trace amounts of TCE were noted after 20 min. After 20 min, the tubing was disconnected from the Tedlar gas bag containing 0.2 ppm of TCE and connected to a Tedlar gas bag containing 2 ppm of TCE. After 16.5 additional minutes, a detectable level of contaminant reached the ITMS and the contaminant level stabilized with 30 sec.

The contaminated tubing was replaced with clean tubing and then connected to the probe for both direct ITMS measurement and CT analysis. The following results were noted:

> Port 1 - TCE = 2.46 ppm, collected using a 3.3-ml/min mass flow rate (19.8 ml total volume drawn), data from a posttest analysis of the CT.
>
> Port 3 - TCE = 2.82 ppm, collected using a 16-ml/min mass flow rate, data from a direct ITMS analysis.

The tests clearly demonstrated the ability to obtain quantitative concentration measurements using both the ITMS and CT and gave support to the use of the MPS for in situ sampling and analysis. The direct ITMS measurement tests using port 3 showed that the nylon tubing absorbed some of the TCE contaminant (3.30 ppm versus 2.82 ppm for 5- and 150-ft lengths of tubing, respectively). Because the measured TCE level at different ports tended to vary, further research is needed to explore how the concentrations measured in the sampling device relate to contaminant distributions in the soil.

Savannah River Site tests

A field demonstration of the MPS and the direct sampling ITMS was conducted at the Savannah River Integrated Demonstration Site (SRS), located near Aiken, SC. The purpose of the field demonstration was to integrate the SCAPS truck and in situ sampling methods for measuring TCE and perchloroethylene (PCE) contamination. The field tests were based on the capability to measure contamination levels of TCE and PCE in situ using the ITMS and CT. Sample analyses during the penetration event will be considered direct sampling/measurement. The demonstration was conducted at SRS, a site with a history of subsurface TCE contamination.

Contaminant sampling at SRS was done at three locations as indicated by Figure 18. The first hole (MS801) was in a noncontaminated area, the second (MS902) near the Air Stripping Plant (contaminated), and the third (MS1003) at the Ohmic Heating Site which had been 93 percent TCE remediated. Soil samples for contaminant verification testing were obtained from a hole adjacent to each MPS hole at corresponding MPS sampling depths. The contaminant concentration levels that were measured in the soil verification samples was compared to those data from the ITMS and CT samples. The water table at this test site was at approximately 200 ft and presented no problem. The maximum sampling depth attempted during this field demonstration was approximately 60 ft.

The MPS was configured with 2 friction breakers, 10 sampling modules, and the TDM. The TDM was positioned directly behind the cone penetrometer followed by alternating ITMS ports and CT ports thereafter. Adapter A, with a friction breaker, was positioned before the TDM and adapter D, with friction breaker, after the sampling modules. The ITMS ports were used for qualitative and quantitative screening, while the CT's were used for quantitative contaminant measurements.

Sampling, using the direct sampling ITMS, took approximately 6 min per sample at the sampling flow rate of approximately 30 ml/min. The tube dead volume between the probe and the ITMS was approximately 200 ml. Minimal pore gas was extracted from clay layers, because clay has a low permeability and only low flow rates could be achieved in clays (<1.0 ml/min under a full vacuum).

Discussions were held with SRS personnel prior to any sampling to determine sampling locations and expected contaminant levels at each location. No contaminant was expected at the first hole (MS801). This hole was used to obtain background contamination levels for the site. The second hole (MS902) and the third hole (MS1003) were expected to have contaminant concentration levels in the soil pore gas below 200-300 ppm.

Hole MS801. Prior to the push, all ports were checked to ensure that they were free of contamination, the ITMS was calibrated through the probe for relatively low contaminant concentration levels (100 ppm) of TCE and PCE,

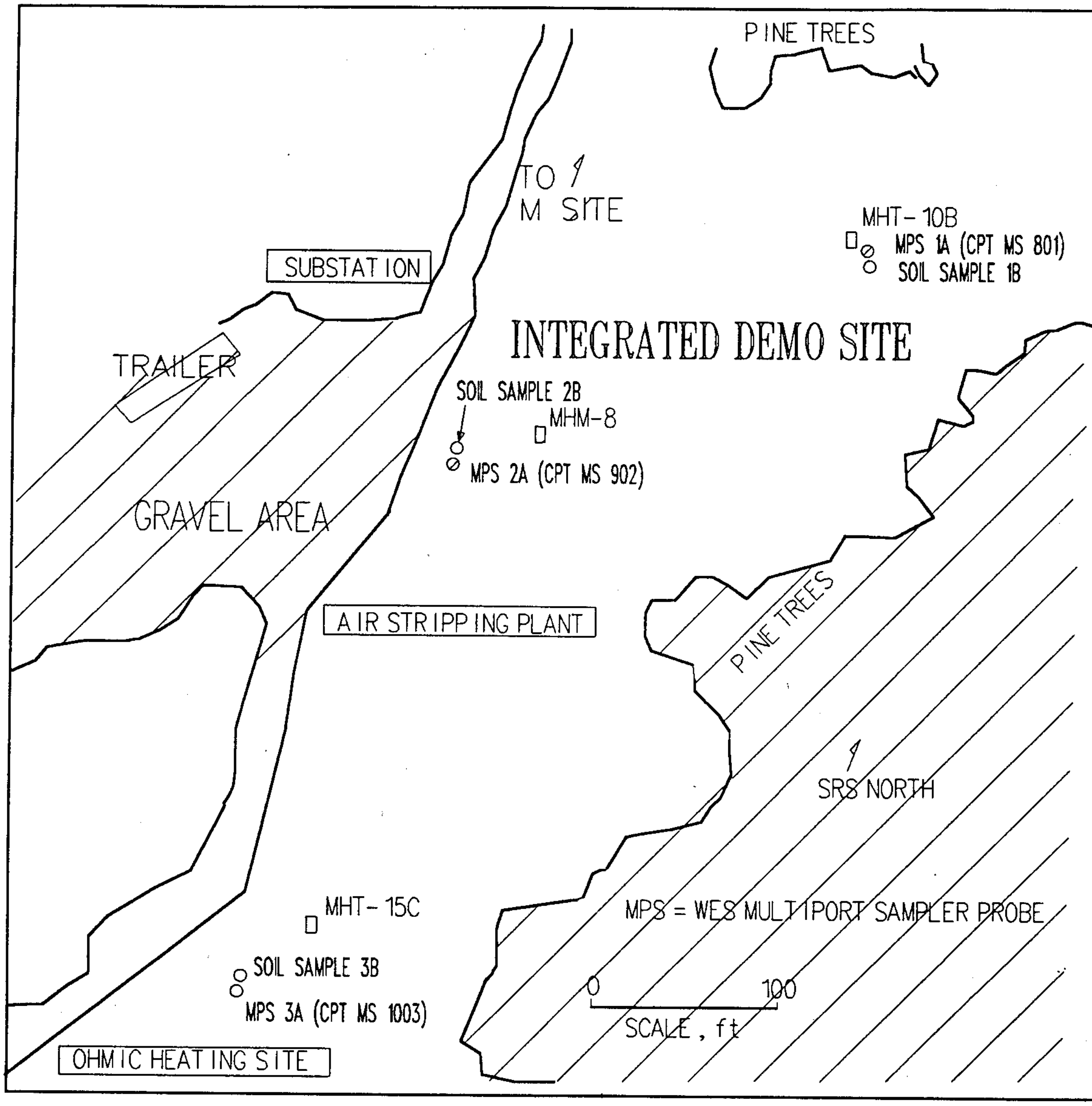
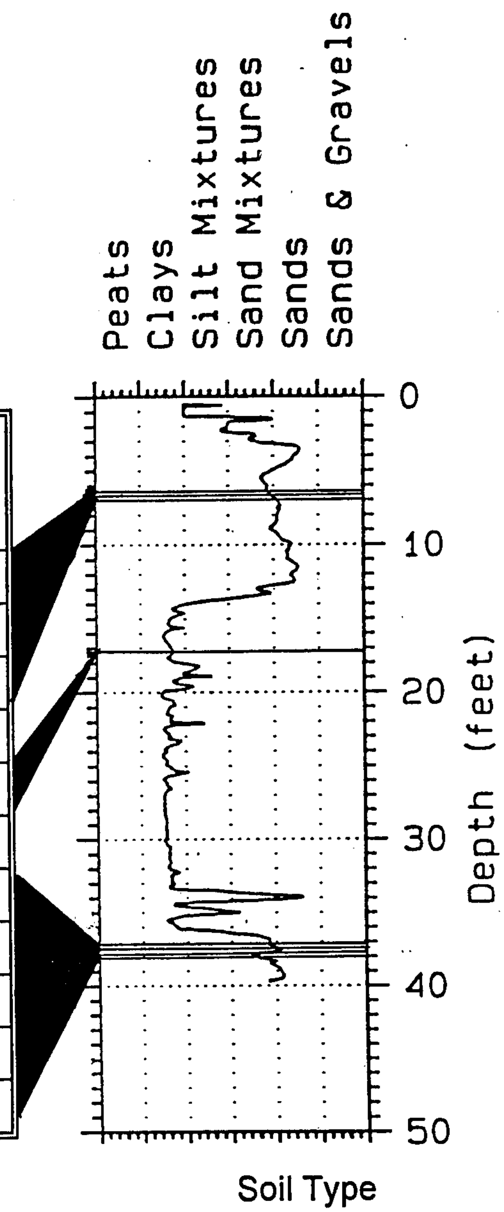


Figure 18. Sampling locations for the field demonstration at Savannah Integrated Demonstration Site

and that all sampling ports sealed under a pressure of 125 psi. The ports were pressurized using clean nitrogen gas. During the push, all ITMS and CT samples were obtained at depths that correspond to sand layers with the exception of the CT sample at 17 ft. At a depth of 38 ft, 96 watts of power were applied to the TDM for 6 min and its effect on the surrounding contaminants was monitored (laboratory tests have shown that 96 watts applied for 5 min caused the TDM to attain a temperature of approximately 200 °F). Figure 19 shows the variation of the soil type with depth, depth type of sample obtained, contaminant, and the concentration of each contaminant for hole MS801.

SAMPLING RESULTS

TCE (ppm)	PCE (ppm	ITMS	CT	SOIL
0.07	0.15		X	
0	0	X		
<0.03	<0.03			X
0.07	0.16		X	
0.07	0.13		X	
0	0	X		
0.08	0.13		X	
0	0	X		
<0.04	<0.04			X



TCE - Trichloroethylene
PCE - Perchloroethylene
ITMS - Ion Trap Mass Spectrometer (direct sampling)
CT - Triple Sorbent Contaminant trap (desorbed into ITMS)
SOIL - Soil sample taken adjacent to MPS hole

Figure 19. Sampling results for the hole MS801 showing soil type classification with depth, depth type of sample obtained, and the concentration of each contaminant

All ITMS samples showed no TCE or PCE present. The CT, however, showed an average of approximately 0.07 and 0.14 ppm of TCE and PCE, respectively. The discrepancy between the ITMS and CT data is due to the

1-percent full-scale (1 ppm) detection limit of the ITMS. The relatively low contaminant concentration levels that were detected by the CT are probably from dispersion of contaminant vapor phases throughout the vadose zone in the site area. The TDM did not appear to increase the concentration levels of TCE or PCE indicating no adsorbed contaminant was present.

After retraction of the probe, calibration of the instrumentation was verified by sampling a known concentration of TCE through port 9 of the probe. The truck was then repositioned and soil verification samples were obtained at complementary elevations from a hole adjacent to MS801. All verification samples showed contaminant concentration levels below equipment detection limits for this hole. Hole MS801 and the verification sampling hole were both tremie grouted after the truck was moved.

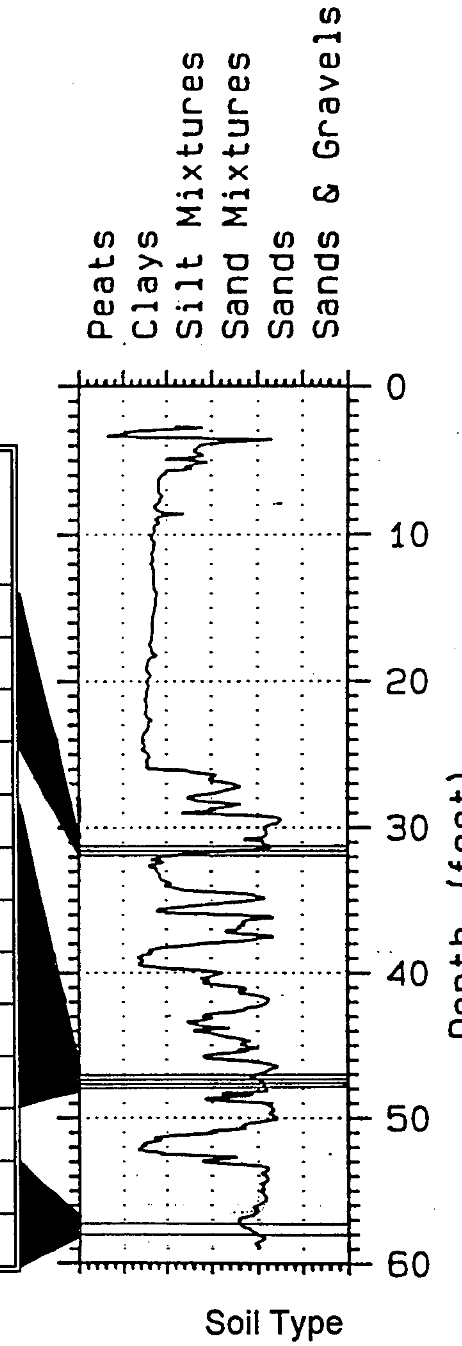
Squirt bottles filled with methyl alcohol, Q-tips, and tweezers were used to clean the ports, specifically those contaminated with silt/clay. The cone and sleeve assembly, CT, and port and piston assemblies were removed from the probe leaving only the MPS sampling modules assembled. The intact modules were put into the sonic cleaner for 30 min for the final cleaning before probe reassembly. The nylon tubing for the sampling modules was cleaned using methyl alcohol and reused.

Hole MS902. Before pushing the probe, the instrumentation was calibrated through the probe for a maximum contaminant concentration level of 500 ppm for TCE and PCE, the ITMS sampling flow rate was preset to 20 ml/min with the port open to the atmosphere, and the ports were pressure checked. Figure 20 shows the variation of the soil type with depth, depth type of sample obtained, and the concentration of each contaminant for hole MS902.

Relatively, low levels of TCE and PCE were sampled by the ITMS and CT at 32 ft, and analytical results were in agreement. At 47 ft, an ITMS sample was taken from port 1 and showed a concentration of 5,700 and 2,178 ppm of TCE and PCE, respectively. Sample concentrations of 4,510 ppm of TCE and 1,771 ppm of PCE were also obtained from port 5 at this depth. These relatively high concentration levels required instrument recalibration after retraction of the probe to quantify these measured values. The direct ITMS measurement obtained from port 5 was taken over a period of 30 min. Contaminant concentration levels initially rose sharply, remained at their respective high levels for approximately 15 min, and then slowly dropped, possibly indicating a depletion of contaminant vapors in the vadose zone around the probe. When the level had dropped to 1,365 ppm of TCE and 394 ppm of PCE, 96 watts of power was applied to the TDM for 5 to 6 min. A slight increase (approximately 10 to 20 ppm) in the TCE and PCE concentrations was observed at port 5 during the use of the TDM. The minor effect of the TDM on the contaminant concentration in the surrounding soil could be due to the relatively low concentration of contaminant in the soil as opposed to the soil pore gas.

SAMPLING RESULTS

TCE (ppm)	PCE (ppm)	ITMS	CT	SOIL
2.4	1.6	X		
<0.013	<0.008			X
10.3	8.9		X	
4510	1771	X		
<0.07	<0.07			X
>128	>56		X	
5700	2178	X		
>48	>28		X	
1.1	0.33			X
2280	1144	X		
>17	>22		X	



TCE - Trichloroethylene
PCE - Perchloroethylene
ITMS - Ion Trap Mass Spectrometer (direct sampling)
CT - Triple Sorbent Contaminant trap (desorbed into ITMS)
SOIL - Soil sample taken adjacent to MPS hole

Figure 20. Sampling results for hole MS902 showing soil type classification with depth, depth type of sample obtained, and the concentration of each contaminant

The truck was repositioned and verification soil samples were obtained from a hole adjacent to the MPS hole (MS902). The soil samples for verification testing showed contaminant concentration levels below detectable limits at all sampling depths except 47 ft. The differences in MPS and the verification sample results suggest that contaminants were mainly in a vapor form and not bound to the soil matrix.

Monitoring tubes were installed in hole MS902 and the verification sampling hole as requested by SRS personnel.

Hole MS1003. The instrumentation was calibrated through the probe for TCE and PCE concentration levels less than 500 ppm. All ports were pressurized to 140 psi (the maximum pressure available from the equipment) and checked for leakage prior to the push. Figure 21 shows the variation of the soil type with depth, depth type of sample obtained, and the concentration of each contaminant for hole MS1003.

During the push, a drop in the port sealing pressure from 140 to 126 psi occurred between 20 and 23 ft. It appeared that all ports were leaking except port 9. Pressure was removed from all ports except 9. ITMS and CT samples were taken at 23 ft. The ITMS sample showed 0.26 and 1.2 ppm of TCE and PCE, respectively. The CT sample showed 1.7 and 7.3 ppm of TCE and PCE, respectively. The low TCE concentration level relative to the PCE level compared to the other sampling locations is probably due to this location being 93-percent TCE remediated.

The probe was advanced to 28 ft, and ITMS and CT samples were taken. The ITMS sample showed 9.2 ppm of TCE and 73 ppm of PCE. The results from the CT sample are not available because a computer malfunction corrupted the CT data and made it unreadable. At 31 ft, ITMS sampling showed 7.4 ppm of TCE and 58 ppm PCE versus 8.5 ppm of TCE and 87.5 ppm of PCE for CT sampling. The amount of remediation of this location again supports the relative contaminate levels between TCE and PCE.

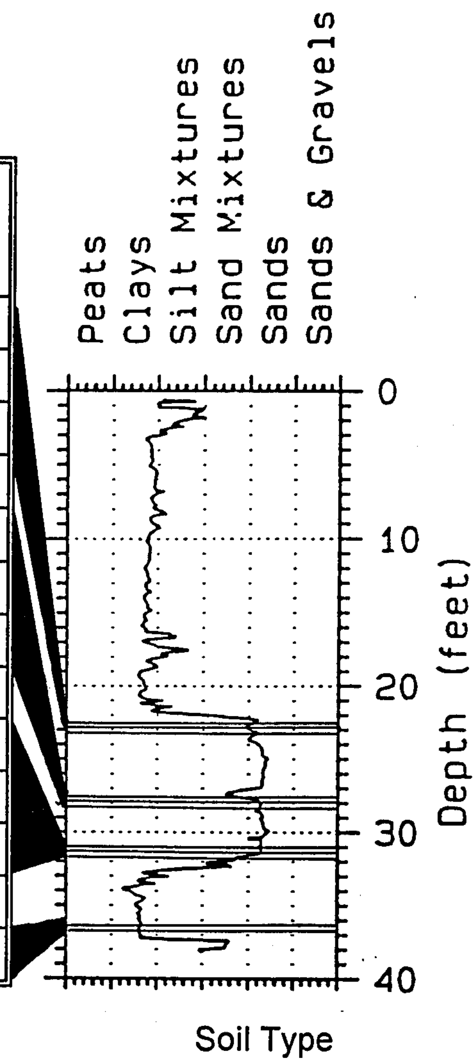
The probe was pushed through a clay layer into a dense sand and could not be advanced any farther than 37.5 ft. ITMS sampling was attempted even though the sampling port was in the clay layer and this layer was impermeable (flow $<$ 1 ml/min at a full vacuum). A contaminant concentration level of about 4.3 ppm of TCE and 20 ppm of PCE was recorded. No CT sampling was attempted because of the low permeability of the clay layer. The probe was withdrawn.

The truck was repositioned to within 1 ft of the MPS hole (MS1003) and verification soil samples were obtained at comparable depths to the MPS samples. The soil samples showed relatively low concentrations of contaminant in the soil. After the truck was moved offsite, the holes were tremie grouted.

All soil samples collected for verification testing were analyzed at WES and ORNL. The results showed contaminant levels that were either low or

SAMPLING RESULTS

TCE (ppm)	PCE (ppm)	ITMS	CT	SOIL
<0.041	<0.015			X
0.26	1.2	X		
1.7	7.3		X	
<0.056	<0.056			X
9.2	73	X		
----	----		X	
0.0076	0.025			X
7.4	58	X		
8.5	87.5		X	
4.3	20	X		



TCE - Trichloroethylene
PCE - Perchloroethylene
ITMS - Ion Trap Mass Spectrometer (direct sampling)
CT - Triple Sorbent Contaminant trap (desorbed into ITMS)
SOIL - Soil sample taken adjacent to MPS hole
---- - Data loss due to computer malfunction

Figure 21. Sampling results for hole MS1003 showing soil type classification with depth, depth type of sample obtained, and the concentration of each contaminant

below detectable limits. Contaminant levels of these magnitudes indicate the contaminants are primarily in the vapor phase or volatized before the soil sample could be obtained from the sampling tube. The lack of contaminant sorbed by the soil matrix is further supported by lack of any increase in contaminant levels when the soil was heated with the TDM.

Follow-up tests at WES

After completion of the SRS field demonstration, field tests were conducted at WES to determine the cause of the port sealing problem. The probe configuration used for these tests differed from that used at SRS in that 6 versus 10 MPS modules were used, no TDM was installed, and no friction breaker was installed following the MPS sampling modules. The probe was first pushed to 60 ft with all ports remaining sealed under a pressure of 125 psi. It was determined that the second friction breaker used above the sampling modules appeared to cause the sealing problem.

To verify that the second friction breaker was the problem, a second friction breaker was added above the sampling modules and a second push was conducted. The probe was pushed to 65 ft and four of the six port seals failed. The second push confirmed the sealing problem was not a problem in the MPS design but was caused by positioning the MPS modules between two friction breakers. The second friction breaker tends to compact the loose soil around the probe creating higher lateral pressures than would normally be obtained.

5 Summary, Conclusions, and Recommendations

Summary

A module that provides an uncontaminated sampling port for obtaining different types of fluid samples and adapts directly to existing SCAPS equipment was designed, constructed, and field tested. Each module has one moving part and is controlled at the ground surface through an independent pressure/sampling tube. The single moving part is a pressure/vacuum activated horizontal piston that is used to seal and open the port. A maximum of 12 modules can be stacked vertically to obtain up to 12 independently operated ports. As the cone penetrometer advances to a desired depth, the modules are selectively opened to allow soil pore vapor to be drawn in. The vapor is then analyzed for targeted contaminants using on-line analytical instruments or collected for off-site analysis and testing. The modules were attached to an ITMS for direct sampling analysis of contaminants during this test program. In this phase of the MPS development, it has only been used to sample gases and vapors in the laboratory and field.

The MPS was laboratory tested to ensure its structural integrity. During the laboratory tests, the probe was hydraulically pushed into a large-scale stress chamber which simulated in situ soil pressures to depths of 250 ft. The probe was pushed during a 4-day period to a maximum simulated depth of 200 ft in sand. During each push sequence, the ports were tested for leaks and their operation. The structural integrity of the probe was sufficient, but minor design changes in the port-piston configuration were made that enhanced their operability and eliminated leakage.

A field test integrating the probe and the SCAPS truck was conducted at WES to determine its operational capabilities. The probe was hydraulically pushed to 25 ft and retracted. During the push, the ports were held in the closed position under air pressure, and no pressure leakage was detected. At the maximum depth, several ports were opened to ensure their operation under field conditions.

The MPS probe was deployed to ORNL to perform laboratory evaluations of the probe's ability to retrieve samples from the vadose zone the quantitative estimates of contaminant concentrations. These tests showed that the MPS

worked as designed and could be integrated with a CT and an ITMS to produce high quality analyses of soil pore gas/vapor.

A field demonstration of the MPS and the ITMS was conducted at the SRS, located near Aiken, SC. The purpose of the field demonstration was to integrate the SCAPS truck and in situ sampling methods for measuring TCE and PCE contamination. Contamination sampling was conducted at three locations. Soil samples for verification tests were taken adjacent to the MPS hole at each location. The contaminant concentration levels that were measured in the soil verification samples was compared to those data obtained from the ITMS and CT samples. Although some operational problems were experienced, the field demonstration proved the capabilities of the MPS.

Follow-up field testing at WES demonstrated that the operational problems experienced at SRS were caused by the addition of a second friction breaker above the MPS sampling modules and were not a problem with the probe design. New operational procedures have eliminated the port sealing problems.

Conclusions

Laboratory and field testing has shown the MPS to be a viable method for sampling vapor and/or gas for contaminant analyses. The MPS is capable of collecting samples for analyses on site or off site in a laboratory at a later time. The ORNL equipment, the CT and the ITMS, interface well with the MPS and will add depth to its usefulness as a site characterization and vapor and/or gas sampling tool.

Recommendations

Although the MPS functions reliably as an in situ sampling tool, modifications should be made to improve its operational capabilities. Areas of possible improvement are:

a. The ports should be independently monitored to determine if/when a port seal ruptures. The control panel should be modified to accommodate either a flow meter or pressure gage or both for monitoring port leakage and isolating and sealing any port that has failed during a push.

b. The nylon tubing in the umbilical cable, which connects the MPS to the surface, can potentially absorb contaminants and is hard to clean. A new umbilical cable should be constructed using tubing which can withstand pressures to 200 psi and does not readily absorb contaminants. Teflon-based tubing does not absorb contaminants at temperatures below 140 °F.

c. A permanent temperature sensing device should be incorporated in the probe to monitor the temperature of the soil surrounding the probe when the TDM is in use.

d. The tube sections that interface the MPS with the umbilical cable are sized to allow staggered connections in the tube housing. Because these sizes have to be precise, there is little flexibility in fabricating and assembling these tube segments. The connections should be redesigned so that all connecting tubes are the same length.

e. Twelve screws are currently used at each connection in the MPS. Removing and replacing screws is the slowest part of the assembly and disassembly procedure. Moreover, the screws tend to become packed with soil during a push and they must be cleaned before they can be removed. A new design is needed that eliminates the 12-screw connection. A possible design is the use of 3 pins in place of the 12 screws. These pins would only be removed after a site investigation or if a module must be repaired or replaced.

f. The MPS sampler module tubing is held in place and sealed at each module using a press fit and compressed o-ring. The diameter of the nylon tubing tends to vary and often only the compression of the o-ring holds the tubing in place. The pressure used to seal the ports can blow the tube loose if the tubing is not sized for the press fit. To prevent tubing blowout and leakage between the module and interface tubing, a new connection design is needed. A design using a coarse shallow thread machined into each module could eliminate the problem. The threaded connection will eliminate the possibility of a tube blowout and increase the flexibility of the overall tubing diameter at this connection point.

g. The modules are fabricated from carbon steel and heat treated for wear resistance, but they corrode easily. The resistance to corrosion can be increased if future modules are fabricated from heat treatable stainless steel.

h. The cleaning and decontamination procedures for the probe are still being perfected and require updating as more experience is gained using the probe with a variety of contaminants.

i. Reliable correlation of data from the CT and ITMS were limited because of the relatively brief field experience with the CT. Further field experience with the CT is needed to develop data on the best flow rates for collecting gas or vapor contaminants from various soil types.

j. The MPS was originally designed to test different types of fluids, and to date only gases have been sampled. Laboratory and field verification tests are needed to prove the ability of the MPS to sample liquids.

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The multiport sampler, developed within the Tri-Services Site Characterization and Analysis Penetrometer System (SCAPS) program, is a cone penetrometer configured with sampling modules. The modules are fitted into the string of penetrometer rods to provide independently controlled sampling ports. Soil gas and/or soil liquids can be drawn into the interior of the penetrometer rod at discrete depth intervals as the cone penetrometer is advanced. A thermal desorption module is designed to heat the soil and volatilize contaminants. The samples are then collected through the ports and analyzed for suspected contaminants.

14. SUBJECT TERMS

Cone penetrometer	Sample volatilization
Contamination	Soil gas sampling
In situ sampling	Soil liquid sampling

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